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CONTENTS

The World's Airway System

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SUMMARY.—Commencing with an historical review of the development of commercial aviation with heavier-than-air machines, and the necessary international control, the paper surveys the achievements of the principal European airway systems, their traffic and financial positions. British overseas air services to India, Australia and South Africa are described. The extent and organization of air traffic and the aids to air navigation in the United States are sketched. The course of events preparatory to a trans-Canada airway and trans-Atlantic communication is outlined, and attention is drawn to the self-sustained air services which have aided in the development of our northern areas.

History will mark the third decade of the twentieth century as a period of amazing progress in transportation. At its opening a journey round the world by the main centres of commerce and including London, New York, San Francisco, Hongkong, Singapore and Calcutta required about seventy days travel. In 1936 the same journey will be possible in fourteen days and before the close of the decade probably in ten.

The purpose of this paper is to give some account of the airway system which has made this revolution possible. It deals with transport by heavier-than-air types of aircraft, i.e., aeroplanes and seaplanes. The air commerce of the world is borne today on these and as yet lighter-than-air types play little part in it. The world's air services may be conveniently dealt with under three headings —European, British Commonwealth and United States. Canadian activities, being of special interest here, and having a somewhat different background, will receive more detailed attention.

A knowledge of the history of aviation is necessary to an understanding of its present position. The influence of two factors, neither of which played any part in the early development of the railway, steamship or automobile, has been abnormal and has disturbed the natural growth of aviation.

One factor is psychological, arising out of the conquest of a new element. Mankind had always travelled on the face of the earth and water and new inventions for doing so came gradually. Their adoption required little mental readjustment. Human flight, though throughout the ages the dream of the poet and scientist, was something entirely new. Even now, after a generation, it still inspires instinctive distrust and hesitation on the part of many, if not an actual majority, of mankind.

It is equally true that the "Conquest of the Air" fired the imagination and generated an enthusiasm on the part of aviation's pioneers which could not be gainsaid. By their devotion, courage and industry every obstacle has been surmounted and the success already achieved justifies their inspiration. It is none the less true, however, that aviation has suffered more from its enthusiasts than from its enemies. Many far too optimistic views have been broadcast of its potentialities. This undue optimism reacted unfavourably and has hindered, rather than helped progress. This phase is now passing and aviation has already taken its place as an essential part of the world's transportation system, administered by business men and operated by skilled staffs with a background of sound technical training and long experience.

The other factor was the conjunction of the Great War with the initial stages of rapid development in aviation. The war was, in fact, the cause of this rapid development and during the adolescence of the aeroplane military requirements alone ruled design and construction. Imagine what might have happened to automobile development had all design been concentrated for a number of years about the beginning of this century on the production of tanks and artillery tractors, or, if for a generation, from 1860, marine engineering had been confined to the production of destroyers and battleships. The effect of this stoppage of all development of civil aviation went even deeper, for, in the case of the automobile and the steamship, the roads and harbours necessary for their movement already existed, whereas in 1914 no airway systems for civil use had even been considered.

Development during the period between December, 1903, the date of the Wright Brothers' first successful power-driven flight, and the outbreak of war in August, 1914, falls naturally into two stages. In the early experimental years, when flying was the hobby of a few enthusiasts, aircraft and engines were unreliable and the technique of flight was being mastered. Funds were lacking for rapid development and the public sceptical that any practical result would be achieved.

On July 25th, 1909, Bleriot flew the English Channel. This flight marked the beginning of more rapid progress. Governments could no longer ignore the potentialities of flight and the fundamental changes it might bring; its influence in future warfare was manifest to the younger generation of military and naval officers and the public crowded to watch exhibitions of flying everywhere. Rapid progress followed, funds for development were forthcoming,

and by 1914 aircraft had reached the stage when they were fairly stable in the air and could be used for observation purposes and limited transport. It is significant, in view of the events of the past few months, that in August, 1914, plans were well advanced for a transatlantic flight.

During the war, civil aviation ceased entirely. There was an immense development of military aviation and a constantly increasing demand for aircraft of higher speed and manœuvrability and greater carrying capacity. There was but little time for research, so that war time progress was more in the production of engines of greater horse power and larger aircraft than in any fundamental improvement in design.

After the armistice, the world found itself with thousands of aircraft and a great body of trained pilots and air engineers for whom absolutely no peace time outlet had been developed. Every nation realized the importance of maintaining its air power. It was impossible to maintain the war strength of the Air Forces and everywhere there was a search for civil work in aviation, not only on its own merits, but as a means of building up a reserve of national air power.

The only outlet in most countries was the carriage of passengers, mail and express between the main centres of population and industry and in Europe a feverish activity ensued in the establishment of such services. This growth was governed more by nationalistic aspirations than by traffic requirements or considerations of sound commercial operation.

Fortunately, at the Peace Conference, the representatives of the allied and associated powers had the vision to foresee the rapid development of air transport and to realize that chaos would result unless there was some agreement among the nations as to the principles which should govern international flying. A sub-committee of the Peace Conference was, therefore, established to study the subject and draft a convention which would provide a basis for development on common standards.

The International Convention for Air Navigation then agreed on lays down certain general principles. Under Article 1, it recognizes that every Power has complete and exclusive sovereignty over the air space above its territory, but under Article 2 accords freedom of innocent passage above its territory to the aircraft of the other contracting states. Under Article 3, each state may forbid its own private aircraft and those of other contracting states from flying over certain areas and under Article 16, each contracting state has the right to establish reservations and restrictions in favour of its national aircraft in connection with the carriage of persons and goods for hire between two points in its territory. The Convention further provides for the registration of all aircraft by contracting states under certain conditions, for their certification of airworthiness, for interstate flying and for the licensing of personnel and other details. It also creates, under Article 34, the International Commission for Air Navigation and defines the method of representation of the contracting parties on that Commission. The duties of the Commission are to receive or make proposals for the modification or amendment of the present Convention, for the interchange of information, for the definition of certificates of airworthiness, the conditions under which pilots' licences shall be issued and to collect and disseminate information of every kind relating to air navigation. Provision was later made under the Convention for member states to enter into agreements with non-member states covering international traffic by air, provided the terms of the original convention are not infringed.

Under this Convention and the International Agreements permitted between member and non-member states, a world-wide system of air lines has been gradually developed. In Europe practically every country has its national Air Service and the British, French, German, Italian, Belgian and Netherlands governments have been specially active. These national air transport companies compete strenuously for traffic and parallel each other's services on many airways. The activities of the International Air Traffic Association, which has been formed by the aircraft operating companies of the different countries for the advancement of their interests, have modified this competition to some extent and by agreements for the exchange of traffic, the issue of through tickets and co-operation in the compilation of time-tables, so as to give convenient connections between one line and another, better co-operation and a more efficient transport system have resulted. Political, strategic rivalry and economic nationalism have, of course, retarded the progress of aviation in Europe very materially. It is only recently that Imperial Airways, for instance, have been able to secure the right to fly across France and Italy on the way to the Far East and South Africa.

The European System

The European airway system only exists by reason of the generous subsidies paid the airway operators by their governments. The exact amount of the contributions made by the different governments is difficult to obtain. Much of it is camouflaged and no two governments pay on the same basis. The following figures, published by the Air Transport Co-operation Committee of the League of Nations, however, show approximately the position in 1933.

Country	Receipts from Customers	Official Subsidies	Financial Autonomy	Load factor* or Coefficient of Utilization
			per cent	per cent
Germany	9,569,399	17,311,071 Reichmarks	35.4	
Austria	454,474	1,486,500 Schillings	23	46
Belgium	5,563,880	16,549,392 Belgian Frcs.	25.2	32
Finland	3,464,982	2,118,900 Finmarks	70	52
France	29,300,000	109,588,000 French Frcs.	21	53
Greece	7,076,354	14,752,667 Drachmas	32	70
Italy	6,889,255	72,377,644 Lire	8.7	42.5
Netherlands	1,241,777	404,268 Florins	76	54.1
Poland	447,993	5,603,215 Zloty	7.4	40.4
Sweden	889,453	970,500 Kroners	48	70
Switzerland	563,733	1,120,702 Swiss Francs	33	47
Czecho-Slovakia	2,415,819	13,860,000 C. Crowns	15	43

The same report, after a paragraph on Imperial Airways, in commenting on the financial position of the European airway system makes an interesting comparison between the Netherlands (K.L.M.) and the Italian systems:—

"Imperial Airways are possibly second to no other European line as regards economic working. It is, however, difficult, in the case of a concern whose main justification lies in Imperial communications, to see what advantage the European lines only have over the rest. Moreover, the British government does not supply separate figures for the revenue earned by each line of Imperial Airways.

"To get an idea, therefore, of the best achievements of air transport in Europe, the proper way is to analyse the returns of the Netherlands K.L.M. for its European network (omitting the Indies line, even as regards its Amsterdam-Athens-Cairo section).

"In 1933, for the whole of its European network, the

*Every aircraft is licensed by its Certificate of Airworthiness to carry a maximum weight which must not be exceeded in flight. The pay load of the aircraft is what is left after deducting from this maximum permissible weight the weight of the aircraft, complete with engines, fittings, etc., crew, fuel and oil. The "co-efficient of utilization" or "load factor" is the ratio between this pay load and the amount of cargo actually carried.

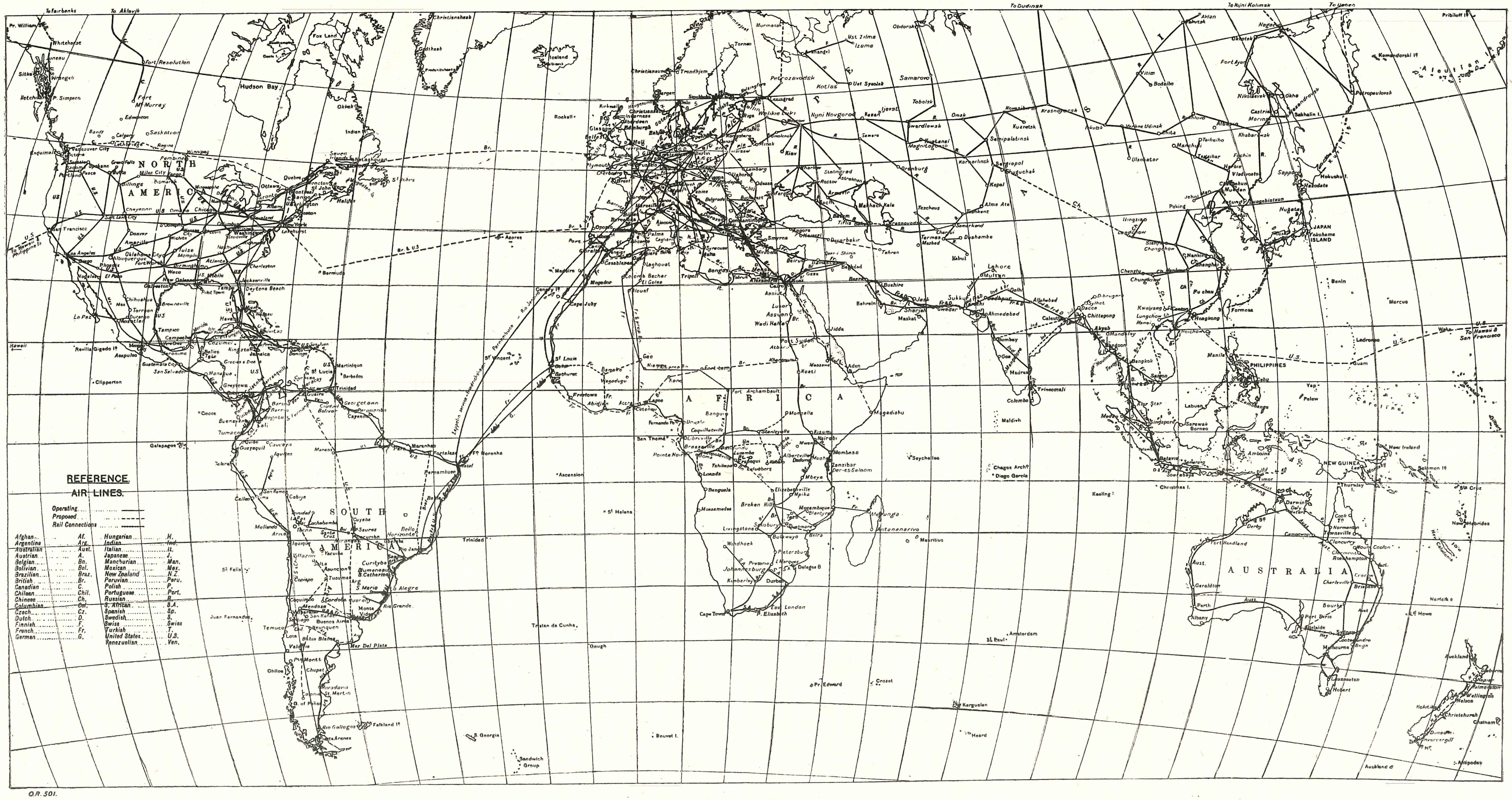


Fig. 1—Principal Air Routes of the World, 1934.

K.L.M. received a subsidy of 404,268 florins. At the same time it earned:

825,182 florins in passenger revenue
305,406 florins in goods revenue
35,309 florins in luggage charges
75,880 florins in mail charges

or 1,241,777 florins total revenue.

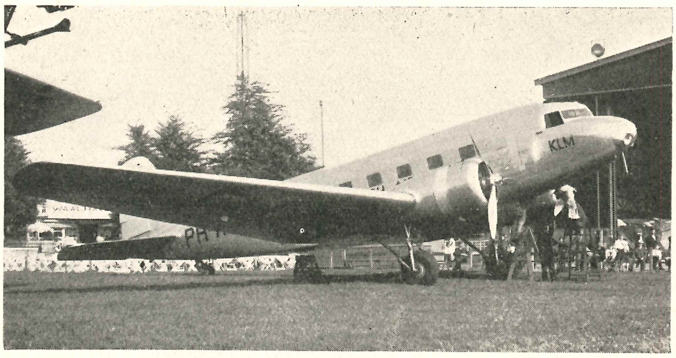


Fig. 2—Douglas Monoplane, used by American Services, K.L.M. in Europe and on East Indies Service. Two 720-h.p. motors. Pay-load 2,555 pounds. Max. speed 213 m.p.h.

"The revenue from traffic therefore amounted to 13 million francs, as compared with 4,100,000 francs government subsidy. The financial autonomy of the line was therefore 76 per cent, and the company is only 24 per cent away from its assumed goal—economic independence.

"This splendid result is mainly due to the comparatively small size of the system served; to the fortunate position occupied by the Netherlands, at the intersection of the most important trade routes for the whole of northern and north-western Europe, which is economically the most active; and to the proportion maintained between the resources employed and the results that can be expected. Additional advantages are the Free Trade system traditional in the Netherlands, and the determination of those in control of the company to have the requisite machines built or purchased, at the proper time and in the proper place.

"In spite of the difficulties of 1934, the K.L.M. would appear to have even bettered during that year the results of 1933. According to press statements, traffic receipts for the whole system covered 82 per cent of total expenses; what is certain is that the traffic figures show a fresh and very striking increase.

"Taking the question from the standpoint of financial return, commercial air lines such as those in Italy seem to be badly handicapped as compared with the K.L.M. As there can be no question of the quality of the personnel and machines, and as such widely different results must be primarily attributed to insuperable differences in economic geography, the author has no hesitation in pointing to the following facts. In 1933, the Italian air services — all covering the territory dealt with in my report — produced 4,360,000 ton-kilometres (or 40 per cent more than the K.L.M.), 1,880,000 of which were utilized. Yet, the Italian revenue from customers does not exceed 9,000,000 francs, as compared with 94,000,000 francs in subsidies. The following table shows the comparison between the two national concerns:

	Per ton-kilometre carried: Receipts from customers Francs	Per ton-kilometre carried: Government subsidy Francs
Netherlands	9.60	3.00
Italy	4.75	50.00

"Thus, for each ton-kilometre carried, the Italian lines require receipts totalling 54.75 francs, whereas the K.L.M. can manage with 12.60 francs. This striking difference is only to a small extent due to the utilization of the tonnage afforded (54 per cent by the K.L.M., 43 per cent by the Italian lines). It is due more to the difference in the rates actually charged: the K.L.M. earns twice as much on every ton-kilometre. Finally, it may be suspected that the machines operated on the Italian lines are expensive to run, and that a great proportion of the ton-kilometres carried pays no, or merely nominal charges. In these circumstances, if transport is the real objective of commercial aviation in Europe, it will be seen that the Italian government pays seventeen times as much as the Netherlands government per unit of actual transport."

The author, Mr. Henri Bouché, concludes his report as follows:—"The European network is still waiting, however, for the most valuable gift that it could receive: a doctrine of collective action calculated on a European scale to meet European needs, and based on strictly economic lines."

A glance at the map showing the European airway systems shows the multiplication of national services, the inevitable result of post-war rivalries and fears. However unsound the economics of the position, from the users' point of view, travel by air is safe, convenient and relatively cheap and the growth of the traffic indicates that air travel and transport has come to stay.

Particulars of five great European systems may be of interest:—

Germany

Germany was prohibited by the terms of peace from maintaining an Air Force. Her whole energy was, therefore, released and devoted to the building up of an internal civil airway system which soon served every considerable town and city in the Reich and spread far afield, till today it operates services to Amsterdam and London; Paris, Marseilles and Barcelona; Copenhagen, Gothenburg and Oslo; Tilsit, Riga and Leningrad; Kovno and Moscow; Vienna, Budapest, Belgrade, Sofia and Salonica; Venice and Rome. Further, the German airway extends to South America via Seville and Bathurst, thence by seaplane and mothership across the South Atlantic to Brazil. On this service the seaplane lands beside the mothership in mid-Atlantic and is hoisted on board, refuelled and launched by catapult to continue its flight.

This method of overcoming the long ocean passage is unique. It has worked successfully for three years now and rumour has it that it may be used to make possible

Traffic Returns German Regular Air Services

Year	Route Mileage	Miles Flown	Passengers		Mail (Including Printed Matter and Parcels)		Goods (Including Newspapers and Excess Baggage)	
			Number Carried	Passenger-Miles	Tons	Tons-Miles	Tons	Tons-Miles
1931	17,900	6,424,012	98,167	15,945,407	399.52	110,028	2,195.52	548,490
1932	16,975	5,758,326	98,489	17,529,948	378.14	96,724	2,085.20	538,034
1933	17,228	6,551,728	123,036	23,828,298	459.92	126,037	2,479.71	650,446
1934	23,442	8,862,766	165,846	38,950,181	759.51	276,687	3,167.17	883,913

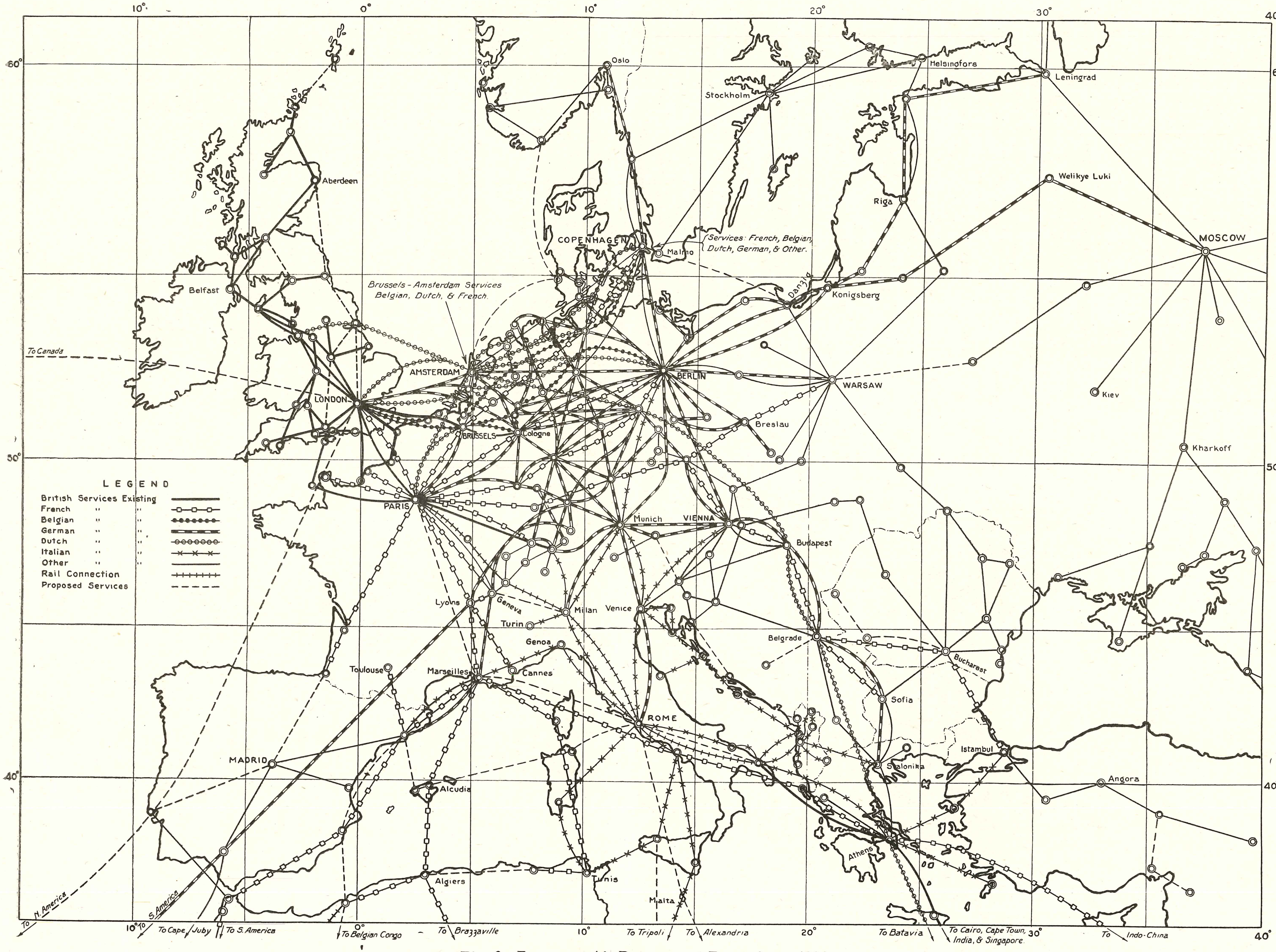


Fig. 3—European Air Routes and Extensions, 1934.

a Germany-United States service. Whether it will prove practical in the stormier North Atlantic waters remains to be seen. If so, it opens great possibilities.

The Russian System

Soviet Russia's area and her inadequate railway and road systems present an opportunity for a remarkable development of air transport which her rulers have been quick to realize. Till 1932 German influence was supreme. "Deruluft," the German-Russian operating company, which still operated the Berlin-Leningrad and Berlin-Moscow lines, was formed in 1921. In 1932 all commercial aviation was unified in "Aeroflot." This organization is really a division of the Soviet Air Force and a system of airways is gradually being built up all along the frontiers of Soviet Russia so as to permit of the easy concentration of her air power at any point from the Baltic along her western and southern boundaries past the Black and Caspian seas to Central Asia and finally to the Pacific coast. On many of these airways the service is as yet only occasional. The trans-Siberian and Afghanistan services are stated to be six times a month each way and other services even less frequent. As in northern Canada, much use has been made of the aeroplane for exploration and reconnaissance and for transportation in the more remote districts. Little up-to-date information is available on Russian progress.

Statistics

Year	Route Mileage	Passengers carried	Mails (tons)
1923	260	2,267	1.82
1925	2,022	5,282	7.78
1928	5,795	8,089	63.80
1930	16,458	12,000	114.81
1931	17,241	19,000	345.89
1932	18,811	27,226	454.00
1933	27,926	41,000	1,673.15

France

The French European network, though not so intensive at home as the German, is even more wide spread, serving London; Rotterdam and Amsterdam; Brussels; Hamburg, Copenhagen and Malmo-Cologne and Berlin; Strasburg, Nuremberg, Prague, Breslau and Warsaw; with an extension from Prague to Vienna, Budapest, Belgrade, Sofia, Bucharest and Constantinople. The French service to Asia traverses the route Paris, Marseilles, Naples, Corfu, Athens, Beirut, Iraq, Persia, India, Burmah to Bangkok and Saigon, while its African lines serve the French possessions in North, West and Equatorial Africa and extend from Natal, paralleling the German service across the South Atlantic to Brazil and the Argentine.

The financial statement of "Air France," the national operating company, for 1934 shows the total cost of operations to have been $14,125,486 and the revenue $14,457,830. Of the revenue $12,838,554 was from state and other subsidies and mail contracts and $1,427,171 passenger and express revenue.

Netherlands

K.L.M., the Netherlands national operating company, is, as has been seen above, one of the most economical and efficient operating companies in the world. It has wisely limited its European operations but serves Holland and the neighbouring countries to great advantage with lines to Berlin; Hamburg, Copenhagen and Malmo; London; Brussels and Paris. Its famous line from Amsterdam to Batavia runs via Leipzig, Prague, Budapest, Belgrade, Athens and Egypt, thence paralleling the British service through Palestine, Iraq, India and Burmah to Sumatra and Java.

On June 1st, 1935, K.L.M. reduced the former eight-day schedule for the Amsterdam-Batavia flight, 8,000 miles, to five and a half days and on July 1st increased the frequency to twice a week, as the traffic justified this. The load factors on this service were, in 1934:—East bound 82.8 per cent; west bound 77.8 per cent.

The British Airway System

The British Isles, because of their changeable climate and limited area and the excellence of the road and railway systems, are not a favourable environment for an airway system. The past two years, however, have seen quite an intensive development of internal unsubsidized air services. This development has only been made possible by the production of multi-engined aeroplanes of comparatively low horse power, capable of carrying a good passenger load in comfort at a comparatively high speed with remarkable reliability and at a low cost per mile.

The British postal authorities too have adopted a very helpful attitude towards air mails and now use air transport wherever the mails can be expedited by so doing. No surcharge is made for such letters and the certainty of a regular revenue from this source has helped the operators materially.

Regular scheduled services are now maintained from London to the Channel Islands; south coast towns as far as Plymouth; Bristol and Cardiff; Birmingham, Liverpool,

Traffic Returns French Regular Air Services

Year	Route Mileage	Miles Flown	Passengers		Mail (Including Printed Matter and Parcels)		Goods (Including Newspapers and Excess Baggage)	
			Number Carried	Passenger-Miles	Tons	Tons-Miles	Tons	Tons-Miles
1931	22,600	5,544,052	32,700	11,447,407	183.66	243,896	1,580.21	495,108
1932	22,845	5,487,512	36,892	13,398,644	170.22	270,338	1,143.93	370,146
1933	21,450	5,986,011	52,179	18,563,243	219.07	326,749	1,487.49	507,743
1934	21,295	6,041,236	50,019	18,482,905	216.01	318,387	1,322.21	462,947

Traffic Returns Holland Regular Air Services

Year	Route Mileage	Miles Flown	Passengers		Mail (Including Printed Matter and Parcels)		Goods (Including Newspapers and Excess Baggage)	
			Number Carried	Passenger-Miles	Tons	Tons-Miles	Tons	Tons-Miles
1931	10,310	1,375,100	11,628	3,133,500	79.43	147,927	704.46	224,863
1932	10,559	1,776,396	14,659	4,342,302	133.75	260,797	578.71	180,025
1933	11,360	2,071,433	32,054	8,587,916	155.89	330,261	891.09	265,466
1934	11,816	2,711,647	57,339	14,245,694	200.45	353,277	785.98	235,641

Isle of Man, Belfast and Glasgow; Manchester and Blackpool, Nottingham and Leeds; Hull, Newcastle, Edinburgh, Aberdeen, Inverness, Wick and Lerwick, and so form a network of internal airlines connecting the main centres of industry and commerce.

The major British effort in civil aviation, however, is that organized during the past eleven years by the government in conjunction with Imperial Airways. Shortly after the armistice the British government subsidized four companies to operate services, three across the Channel to Europe and one to the Channel Islands. In 1924 this arrangement was terminated and a new company, Imperial Airways, was formed to undertake all external air services. The remarkable and almost continuous growth of Imperial Airways is, perhaps, most simply illustrated by the increase in their traffic in ton miles.

Year (ending March 31st)	Traffic Ton Miles
1925	391,032
1926	393,937
1927	512,967
1928	583,668
1929	803,192
1930	1,017,773
1931	900,793
1932	1,251,753
1933	2,196,722
1934	2,733,603
1935	3,511,528

Imperial Airways' services form an important part in the European system. Regular lines are operated—London-Paris; London, Paris, Basle and Zurich; and London-Brussels, Cologne, Leipzig, Prague and Budapest. The relative importance and efficiency of the British service is shown in the returns of the cross-channel traffic. In 1934, 14,682 flights were made, on which 102,667 passengers were carried by British, French, German, Dutch and Belgian regular services. Forty-six per cent of these flights were made by British aircraft and they carried 57 per cent of the traffic.

The Indian and Australian Service

Important as these European services are, the major part of Imperial Airways' work is on the Empire services to India and Australia and to South Africa. These have

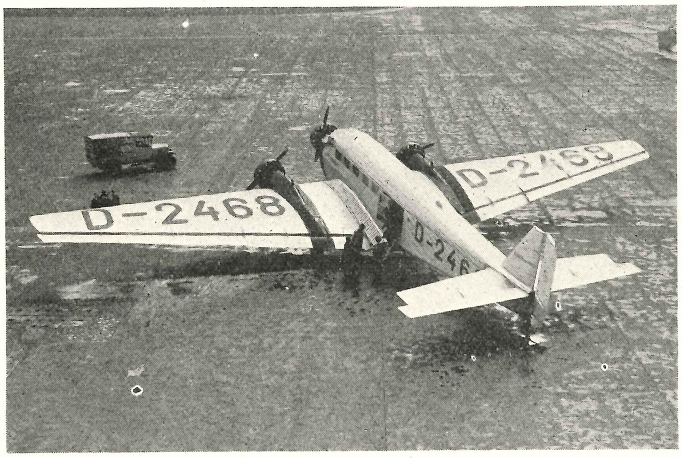


Fig. 4—Junkers 52 Monoplane. Three 700-h.p. motors. All-up Weight 20,900 pounds. Max. Speed 180 m.p.h.

been built up since 1929, when the service to India was inaugurated. It was extended first across India to Calcutta, then to Rangoon, next to Singapore, and finally, during 1935, linked up there with "Quantas" Empire Airways, an associated Australian company who operate the Singapore-Brisbane service. This is the longest continuous airway in the world—12,750 miles. Traffic on the Indian section has quadrupled in the five years since its inauguration and the frequency was increased in 1935 from once a week in each direction to twice a week. Traffic on the Australian section has so far surpassed expectations that negotiations are now in hand to place this section on a twice a week basis as well.

The Australian government has assisted the development of a wide spread system of domestic services linking

Fig. 5—D.R. Draco used by British and Australian Services. Four 205-h.p. motors. Pay-load 2,480 pounds. Max. Speed 170 m.p.h.

the principal cities of the Commonwealth and also serving many isolated communities. A regular service to Tasmania has been established and an extension to New Zealand is now under consideration so that the all-British communities in the antipodes may have the benefit of the improved system of communication and transport.

The South African Service

The London-Cape Town weekly service—7,900 miles long—was opened for service in 1932 and has been equally successful. The traffic on it doubled during the first two years and the increase in traffic has been so great as to necessitate the inauguration of a twice a week service from January 1st, 1935.

Under the Empire Air Mail Scheme which has been under consideration during recent months by the Dominion and Colonial governments concerned and which is now agreed to by all, all first class mails will be carried without surcharge. The advance proposed under this scheme is clearly seen from the following table:—

Empire Air Mail Scheme

Provisional Journey Schedules and Frequencies

A = With present day equipment. B = Medium night flying equipment. C = Extensive night flying equipment.

Route	Times taken by Services in July, 1934.		Estimated times to be taken under new Scheme			Number of Air Services per week (July, 1934)	
	Air	Surface	A	B	C	Existing	Proposed
	Days	Days	Days	Days	Days		
1. London-Sydney	14	31	10¼	8½	7¼	None	Two
2. Sydney-London	13	31	9½	7¾	6¼	None	Two
3. London-Singapore	10	23	6¼	5½	4¾	One	Three
4. Singapore-London	10	23	6¼	4¾	4¼	One	Three
5. London-Karachi	6¼	16	3¼	2¾	2½	One	Four
6. Karachi-London	6¼	16	2½	2¼	2¼	One	Four
7. London-Capetown	10¼	17	7	5	4¼	One	Two
8. Capetown-London	10¼	17	6¼	5	4½	One	Two
9. London-Kisumu	6¼	22	4¼	2½	2½	One	Three
10. Kisumu-London	7¼	22	3¾	3¼	2¾	One	Three

The cost is estimated to be as follows:—

	United Kingdom Payment	Other Governments	Total
	£	£	£
1st year............	463,000	287,000	750,000
2nd "	388,000	287,000	675,000
3rd "	313,000	287,000	600,000
4th "	238,000	287,000	525,000
5th "	163,000	287,000	450,000

In 1934 Imperial Airways aircraft flew more than 3,500,000 miles and in 1935 the total will exceed 6,000,000

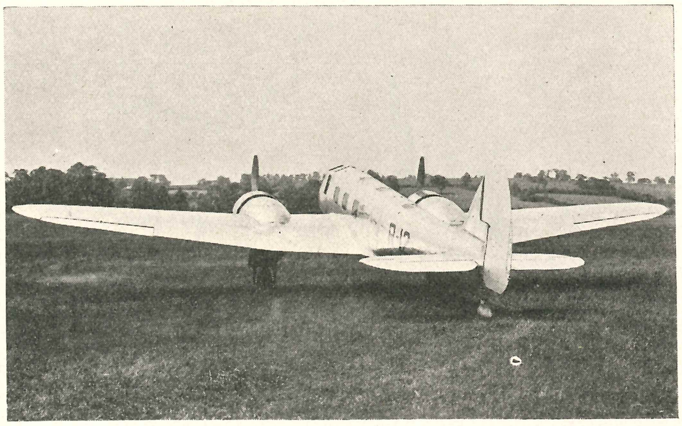


Fig. 6—Bristol Monoplane. Latest British Transport Type. Two 775-h.p. motors. Max. Speed 260 m.p.h.

miles. Taking the cost per ton mile in 1925 as 100 the cost is today 40. This reduction has been achieved principally by the intensive use of each aircraft in their service. The number of these is very small as compared with many other services but each machine is kept as many hours in the air as possible. Each of the four-engined Handley Page type, which is one of the mainstays of the service, averaged eighteen hundred and ten hours in the air during 1934.

Imperial Airways have now under consideration a service to Nigeria and other West African colonies, a trans-Atlantic service and other extensions. The company have always adopted a forward policy. It believes in large units with the best speed the traffic will bear, but considers safety, regularity, comfort and low rates of more importance than speed. They were the first to introduce the three-engined and then the four-engined aircraft. The new aircraft now under construction to enable the Empire Air Mail Scheme to be inaugurated in a year's time include 29 four-engined flying boats of a carrying capacity of from 3½ to 5 tons pay load, depending on the fuel required, and 11 four-engined monoplanes, all fitted to carry, with the utmost comfort, which is very necessary on such lengthy journeys, 27 passengers by day and with sleeping berths for 20 by night. Meals will be prepared and served in flight, just as in a dining car.

To sum up Imperial Airways' operations:—

(1) Its aircraft have now flown over 18,500,000 miles;
(2) It serves 24 countries in four continents;
(3) It employs over 1,800 people;
(4) The staff is spread over 50 stations;
(5) It has dealings in more than 20 currencies;
(6) The salaries and wages bill exceeds £350,000 per annum;
(7) Its aircraft used over 2,500,000 gallons of fuel last year.
(8) It carried over 15,000,000 letters last year.

Further, Imperial Airways and subsidiary and associated companies:—

(*a*) Are flying an average of 17,000 miles per day;
(*b*) Operate daily services in Great Britain and to France, Switzerland, Belgium, Germany, Austria and Hungary with connections to all parts of Europe;
(*c*) Operate four services a week to Greece and Egypt;
(*d*) Operate twice weekly to Palestine, Iraq, India, Burma, Siam and Malaya and once weekly to Australia;
(*e*) Operate twice weekly to Anglo-Egyptian Sudan, Uganda, Kenya Colony, Tanganyika Territory, Northern and Southern Rhodesia and the Union of South Africa;
(*f*) Operate ancillary and special services in Africa, Asia, Australia and Newfoundland.

The company received subsidies of £561,000 and earned a profit of £133,769 during the year ending March 31st, 1935, and paid a dividend of 7 per cent on its issued share capital of £624,080.

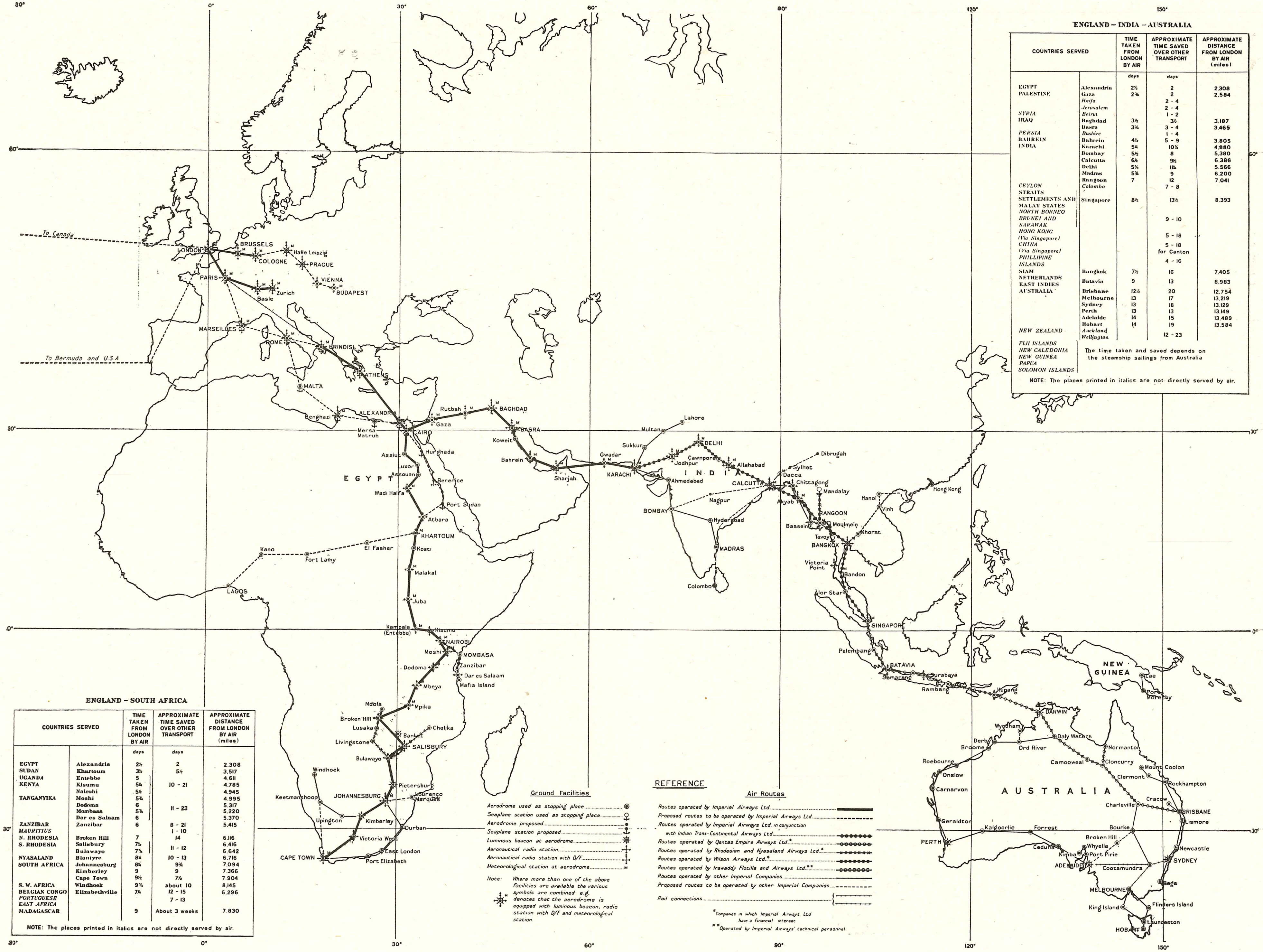
The United States Airway System

Nowhere are circumstances so favourable for the development of air transport as in the United States. A large continental area in a temperate climate, under a common government, with no customs or language barriers,

Imperial Airways Ltd.
Total Traffic Statistics for all Regular Services
(Total route mileage, 1934: 14,823)

Period	Aircraft miles flown	Passengers carried (individual)	Passenger miles flown	TON		MILES		Average load (tons)	Average engine horse power per aircraft flight
				Freight	Mails	Passenger	Total		
1924 (vi)	699,900	(viii)	2,482,000	129,100 (vii)		221,600	350,700	0.5	500
1925	805,300	11,027	2,645,000	147,600 (vii)		236,200	383,800	0.5	500
1926 (v)	733,000	16,621	3,746,000	159,000 (vii)		334,500	493,500	0.7	800
1927 (v)	719,000	19,005	4,296,000	153,100 (vii)		386,500	539,600	0.7	900
1928	911,300	27,303	6,477,000	178,600	36,900	583,300	798,800	0.9	1,000
1929 (iv)	1,166,000	28,484	7,147,000	218,600	126,800	648,900	994,300	0.9	1,200
1930	1,104,900	24,027	6,003,000	196,200	180,000	545,500	921,700	0.8	1,200
1931 (iii)	1,276,900	23,817	7,009,000	200,500	214,900	645,400	1,060,800	0.8	1,400
1932 (ii)	1,733,700	45,844	15,954,000	252,700	277,200	1,483,900	2,013,800	1.2	1,700
1933 (i)	1,926,000	54,768	20,228,000	326,200	406,200	1,891,700	2,624,100	1.4	1,800
1934 (i)	2,315,100	54,875	22,411,000	378,500	663,000	2,110,900	3,152,400	1.4	1,700

(i) Egypt-India service extended to Singapore in July, 1933. Traffic includes the service east of Karachi which is operated by Imperial Airways Ltd., and India Trans-Continental Airways Ltd.
(ii) Egypt-South Africa service extended from Kisumu to Cape Town in January, 1932.
(iii) Egypt-South Africa service commenced as far as Kisumu in March, 1931.
(iv) London-Egypt service commenced April, 1929. Egypt-Basra service extended to Karachi (India) in April, 1929.
(v) Egypt-Basra service commenced 27th December, 1926; flights in 1926 included in total for 1927.
(vi) April-December.
(vii) Separate figures for mails and freight not available.
(viii) Records not available.



ENGLAND – INDIA – AUSTRALIA

COUNTRIES SERVED		TIME TAKEN FROM LONDON BY AIR	APPROXIMATE TIME SAVED OVER OTHER TRANSPORT	APPROXIMATE DISTANCE FROM LONDON BY AIR (miles)
		days	days	
EGYPT	Alexandria	2½	2	2.308
PALESTINE	Gaza	2¾	2	2.584
	Haifa		2 - 4	
	Jerusalem		2 - 4	
SYRIA	*Beirut*		1 - 2	
IRAQ	Baghdad	3½	3½	3.187
	Basra	3¾	3 - 4	3.465
PERSIA	*Bushire*		1 - 4	
BAHREIN	Bahrein	4½	5 - 9	3.805
INDIA	Karachi	5¼	10¾	4.880
	Bombay	5½	8	5.380
	Calcutta	6½	9½	6.386
	Delhi	5¾	11¼	5.566
	Madras	5¾	9	6.200
	Rangoon	7	12	7.041
CEYLON	*Colombo*		7 - 8	
STRAITS SETTLEMENTS AND MALAY STATES	Singapore	8½	13½	8.393
NORTH BORNEO BRUNEI AND SARAWAK			9 - 10	
HONG KONG (Via Singapore)			5 - 18	
CHINA (Via Singapore)			5 - 18 for Canton	
PHILLIPINE ISLANDS			4 - 16	
SIAM	Bangkok	7½	16	7.405
NETHERLANDS EAST INDIES	Batavia	9	13	8.983
AUSTRALIA	Brisbane	12½	20	12.754
	Melbourne	13	17	13.219
	Sydney	13	18	13.129
	Perth	13	13	13.149
	Adelaide	14	15	13.489
	Hobart	14	19	13.584
NEW ZEALAND	*Auckland* *Wellington*		12 - 23	
FIJI ISLANDS *NEW CALEDONIA* *NEW GUINEA* *PAPUA* *SOLOMON ISLANDS*	The time taken and saved depends on the steamship sailings from Australia			

NOTE: The places printed in italics are not directly served by air.

ENGLAND – SOUTH AFRICA

COUNTRIES SERVED		TIME TAKEN FROM LONDON BY AIR	APPROXIMATE TIME SAVED OVER OTHER TRANSPORT	APPROXIMATE DISTANCE FROM LONDON BY AIR (miles)
		days	days	
EGYPT	Alexandria	2½	2	2.308
SUDAN	Khartoum	3½	5½	3.517
UGANDA	Entebbe	5	10 - 21	4.611
KENYA	Kisumu	5¼		4.785
	Nairobi	5½		4.945
TANGANYIKA	Moshi	5¾	11 - 23	4.995
	Dodoma	6		5.317
	Mombasa	5¾		5.220
	Dar es Salaam	6		5.370
ZANZIBAR	Zanzibar	6	8 - 21	5.415
MAURITIUS			1 - 10	
N. RHODESIA	Broken Hill	7	14	6.116
S. RHODESIA	Salisbury	7½	11 - 12	6.416
	Bulawayo	7¾		6.642
NYASALAND	Blantyre	8¼	10 - 13	6.716
SOUTH AFRICA	Johannesburg	8¼	9¾	7.094
	Kimberley	9	9	7.366
	Cape Town	9½	7½	7.904
S. W. AFRICA	Windhoek	9¾	about 10	8.145
BELGIAN CONGO	Elizabethville	7¼	12 - 15	6.296
PORTUGUESE EAST AFRICA			7 - 13	
MADAGASCAR		9	About 3 weeks	7.830

NOTE: The places printed in italics are not directly served by air.

Fig. 7—Imperial Air Routes, 1934.

with a high standard of living and intelligence, many populous cities and industrial areas well distributed over the country, and a mechanically minded population accustomed to travel and already used to long journeys on business or pleasure by road and rail. Under these conditions it is natural that aviation has made giant strides in the United States and that there has been built up during the past nine years an airway system unrivalled elsewhere.

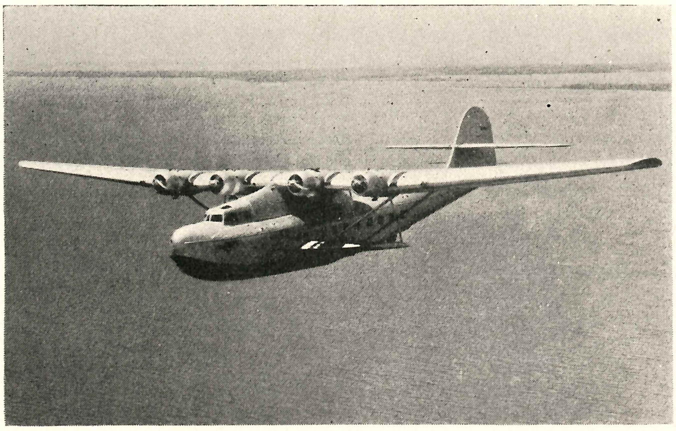


Fig. 8—Glenn Martin Clipper. Four 800-h.p. Motors. All-up Weight 51,000 pounds. Max. Speed 180 m.p.h. with Fuel for 3,200 Miles.

The United States was slower in starting its airway system than other countries, because there was no Federal Air Law till 1926 and no co-ordinated and State-assisted system was possible in advance of legislation. Between 1918 and 1926, however, the U.S. Post Office had built up its own transcontinental air mail system from Hadley Field, N.J., 30 miles from New York, to Oakland, California, a distance of some 2,600 miles, and had lighted it for night flying as far west as Salt Lake City, 2,041 miles. In 1927 the Bureau of Air Commerce was formed and given power to build and equip a national airway system to be operated under licence by commercial firms who contract for the carrying of mails by air with the Post Office. On July 1st, 1935, the system included 20,769 miles of fully lighted and radio-equipped airways. There are four transcontinental systems:—

(1) Boston, Albany, Buffalo, Detroit, Chicago, St. Paul, Spokane and Seattle.
(2) New York, Cleveland, Chicago, Salt Lake and San Francisco.
(3) New York, St. Louis, Kansas City, Albuquerque, Los Angeles.
(4) Washington, Atlanta, Fort Worth, El Paso, San Diego.

and many north and south connections.

The outstanding features of the federal airway system are its lighting, meteorological service, radio beam and two-way services. There are 185 first order meteorological stations and 335 airway weather stations, all interconnected by radio and teletypewriter. Airway forecasts are broadcast every six hours based on the data collected from all over the continent. A recent report* of a flight made on November 13th, 1935, over the Pacific Coast airway may be of interest:—

"Prior to the aircraft's departure the pilot obtains from the despatcher a concise report giving him the heights at which he is to fly over different legs of the journey, the weather conditions at the airports and intermediate stations over which he will pass or land; the ceiling, the direction of winds, the type of clouds and temperature. Should the pilot receive instructions to proceed and not deem the weather suitable, he can reject the despatcher's instructions—on the other hand, should the pilot wish to proceed the despatcher can retain the aircraft on the ground until he deems the weather is suitable. This procedure is carried out on the instructions of the United States Department of Commerce and no flight may be undertaken unless the weather conditions are deemed suitable by both the despatcher and the pilot.

The pilot then leaves the ground, climbing immediately to the ceiling height at which he is to fly, and must fly at that altitude and on the course designated. This is very strictly adhered to. During the flight the pilot or co-pilot, as the case may be, must make out a detailed report of the weather as found at that height. Should he run into adverse weather conditions which were previously unforeseen, he must immediately report same to the ground station and state the nature of the conditions he has encountered, then he will be instructed how to proceed.

On the invitation of the pilot the writer changed places with the co-pilot and received some instruction on the use of the Sperry Artificial Horizon instrument, and also on the Directional Gyro Compass. The gyro compass is apparently very necessary in conjunction with the ordinary magnetic compass, as the magnetic compass fluctuates considerably and in the four or five different aircraft in which the writer acted as co-pilot, they all seemed to function the same.

The majority of United Air Lines' aircraft are now equipped with self-adjusting, three-bladed propellers and once the engines are opened up to their cruising rate of approximately 2,000 r.p.m., with an intake manifold pressure of twenty-eight pounds, whether climbing or diving the propeller adjusts itself accordingly and eliminates excessive strain on the engine while giving a maximum of performance.

The advantage over the old type of adjustable propeller is that the old type had only two settings —one for take-offs and the other for cruising—at the same time the engine had to be throttled down in order to adjust from one setting to another. Now the engines are opened up with the propellers adjusted at the correct position for giving the maximum performance at take-off. When the aircraft has reached the desired altitude the pilot moves two levers which throw in the automatic operating mechanism.

The system of radio communication is a most desirable asset, as the pilot can, while wearing his headphones, receive his beam signal, which is a steady monotone combination of signal "A" and "N," and at intervals of about every three minutes the designated signal of the beam station is repeated three times in quick succession. This signal is one of the letters of the Morse code. Should the pilot deviate to the left from his beam path he is immediately notified by the station sending out the letter in Morse code—"A." Should he deviate to the right he immediately receives in Morse code the letter "N." This system is commonly known as the "A" and "N" system.

Every fifteen minutes on the Pacific run the pilot calls the aerodrome to which he is heading, giving his weather report, as he finds it, the type of cloud formation, direction of the wind, the height at which he is flying and the atmospheric temperature. The operator at the airport immediately replies by saying "O.K." and repeats to the pilot the message received and in turn notifies the pilot of the weather conditions at the airport, direction of wind, height of clouds, type of clouds, visibility, whether hazy, foggy or clear, and

*By the District Inspector, Civil Aviation, Vancouver.

the barometric pressure of the airport. This barometric pressure is necessary in order that the pilot may adjust one of his two sensitive altimeters to be used in landing.

On approaching the aerodrome the pilot advises the operator his approximate location and approximate time of arrival. The operator then proceeds out on the field and by a system of remote control notifies the pilot whether or not he can hear the engine, again repeating the weather conditions. Should the operator be able to hear the aircraft he notifies the pilot to lower his wheels. This is more or less routine procedure and is carried out on all flights irrespective of weather conditions, visibility and whether it is daylight or dark.

Should the visibility be such that it is necessary to come in to the beam station with a very low ceiling at the airport, then the beam directs the aircraft to and over the beam station, which is usually located approximately a mile to two miles from the airport proper—then by a definitely planned routine the aircraft is turned to the right or left, no turns being made with over a 10-degree bank, and allowing ten seconds for entering the turn. The turn is continued until the boundary lights are visible.

In case it is necessary to make a blind landing, which is never done except in dire emergency, the pilot, by means of a two-way switch, changes his wave length to locate the landing beam and continues his turn until he picks up the new signal, flying on this course away from the centre of the airport until he picks up the first and second vertical beams, which are located at the boundary and about fifteen hundred feet from the boundary along the flight path towards the landing strip, then by a wide turn he relocates the landing beam and proceeds down this flight path until the boundary signal is received, and by this time he is in a position to flatten out for his landing."

Should anyone have doubts about the organization of this system let him listen in any evening on a good short wave radio set and hear for himself the pilots reporting their positions and weather every fifteen minutes and receiving from the ground their weather reports and orders as to altitude and landing instructions. It is a fascinating amusement.

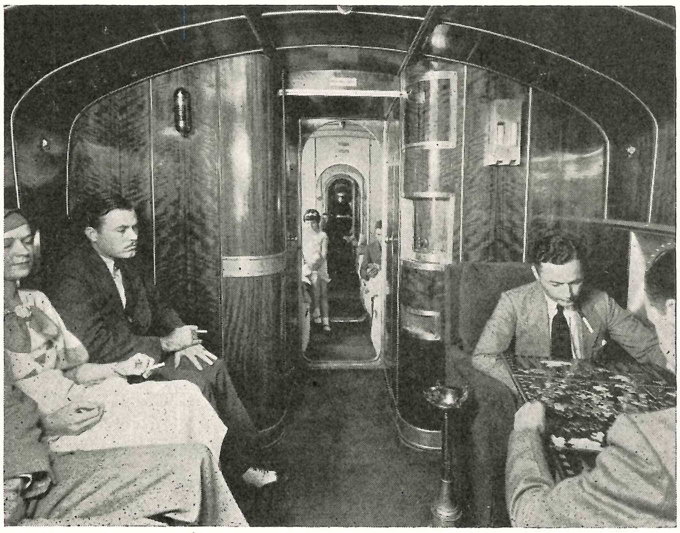


Fig. 9—Interior of Glenn Martin Clipper. Pay-load 4,824 pounds.

The volume of air mail increased from 800,000 pounds in 1926 to 9,500,000 pounds in the peak year, 1931, and has since remained nearly constant at a little less than 8,000,000 pounds. The ton mileage of mail in 1934 was 2,461,411.

Including all domestic and foreign connections, the U.S. air mail system on July 1st, 1935, extended over 46,629 miles. The daily average of miles flown under mail contracts was 129,654, including 16 domestic routes and 13 foreign routes, serving Canada, the West Indies, Mexico, Central and South America. Coast to coast service in fifteen hours is now the rule on the major services and cruising speeds have doubled in eight years from 90 to 180 miles per hour on such lines. Passenger traffic has increased from 5,782 in 1926 to 561,370 in 1934, while the passenger rates have fallen from an average of twelve cents per mile till they are no more than first class rail fare plus Pullman and meals, or an average, on July 1st, 1935, of 5.9 cents per mile. The air express business in the United States has great possibilities and its real exploitation has as yet hardly begun. It has increased, however, from 3,555 pounds in 1926 to 3,449,675 pounds in 1934.

Space does not permit of a fuller description of the advances made in air transport in the United States at this time. The full story may be seen in a bulletin issued by the United States Department of Commerce entitled "Civil Aeronautics in the United States," dated August 1st, 1935, from which the following figures are taken:—

STATISTICS OF CIVIL AVIATION IN THE UNITED STATES

	1931	1932	1933	1934
Airways (all)				
Total mileage:				
Domestic	30,450	28,550	27,812	28,084
Foreign extensions	19,948	19,980	19,875	22,717
Accidents:				
Number of passenger fatalities	26	25	8	21
Passenger miles flown per passenger fatality	4,770,876	5,862,103	24,850,010	10,727,026
Express and freight carried (pounds):				
Domestic	788,059	1,033,970	1,510,215	2,133,191
Foreign	363,289	566,851	942,597	1,316,484
Mail:				
Carried by contractors:				
Domestic (pounds)	9,097,411	7,393,257	7,362,180	....
Foreign (pounds)	545,800	515,466	454,352	....
Mail income to contractors:				
Domestic	$19,900,251	$19,294,332	$16,467,216	$8,813,542
Foreign	6,983,792	6,939,989	6,946,475	....
Mail income average per contract mile flown (domestic)	$0.70	$0.56	$0.43	$0.37
Miles flown:				
Domestic routes	42,755,417	45,606,354	48,771,553	40,955,396
Foreign routes	4,630,570	5,326,613	5,870,992	7,831,155
Passenger-miles flown:				
Domestic	106,442,375	127,038,798	173,492,119	187,858,629
Foreign	13,526,202	19,513,789	25,307,960	37,408,930
Passengers carried:				
Domestic	469,981	474,279	493,141	461,743
Foreign	52,364	66,402	75,799	99,627
Airports:				
Total airports in operation	2,093	2,117	2,184	2,297
Communications:				
Radio broadcast stations	56	61	68	71
Radio range beacon stations	47	68	94	112
Radio marker beacons	46	74	77	84
Weather reporting, airway and airport stations—				
Weather Bureau and Department of Commerce operated, long line teletypewriter equipped	234	234	205	206
Miles of teletypewriter service	13,186	13,500	12,064	11,631
Airway lighting:				
Beacons: Revolving	1,460	1,623	1,510	1,324
Intermediate landing fields, lighted by Department of Commerce	385	337	246	259

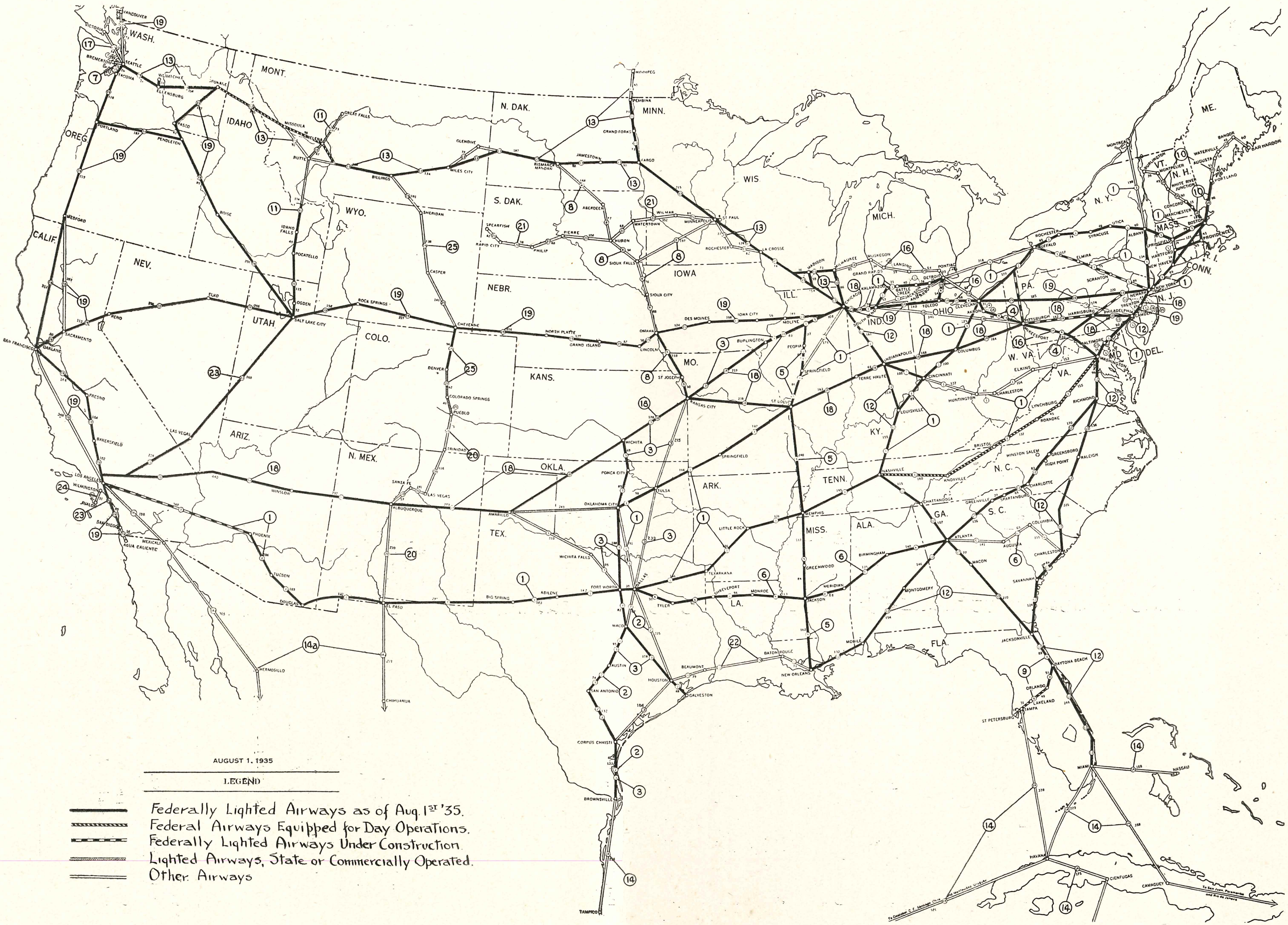


Fig. 10—Air Routes of United States 1935.

Route No.	Operator	Routes Operated	Route Mileage	Class of Service
(1)	American Airlines, Inc.	New York to Fort Worth (via Washington and Nashville)	1466	MPE
		Fort Worth to Los Angeles	1293	MPE
		New York to Chicago (via Buffalo and Detroit)	754	MPE
		Detroit to Chicago (via Kalamazoo)	263	MPE
		Chicago to St. Louis	257	MPE
		Chicago to Fort Worth (via Peoria, St. Louis, Tulsa and Oklahoma City)	950	MPE
		New York to Boston (via Springfield, Mass.)	206	MPE
		New York to Boston (via Hartford and New Haven)	209	MPE
		Boston to Cleveland (via Albany and Buffalo)	637	MPE
		Cleveland to Nashville (via Columbus and Louisville)	469	MPE
		Washington to Chicago (via Cincinnati and Indianapolis)	684	MPE
		New York to Montreal	332	MPE
(2)	Bowen Air Lines, Inc.	Fort Worth-Dallas to Brownsville	551	PE
		Fort Worth-Dallas to Houston	255	PE
(3)	Braniff Airways, Inc.	Chicago to Kansas City	410	MPE
		Chicago to Dallas (via Kansas City, Wichita and Oklahoma City)	964	ME
		Amarillo to Fort Worth	315	MPE
		Dallas to Brownsville	546	MPE
		Waco to Galveston	206	MPE
		Kansas City to Dallas (via Tulsa)	254	PE
		Houston to Corpus Christi	186	PE
(4)	Central Airlines, Inc.	Washington to Detroit	469	MPE
(5)	Chicago & Southern Air Lines Inc.	Chicago to New Orleans (via Peoria)	872	MPE
(6)	Delta Air Corporation	Charleston, S.C. to Dallas	1065	MPE
(7)	Gorst Air Transport, Inc.	Seattle to Bremerton	15	PE
(8)	Hanford Tri-State Air Lines, Inc.	St. Paul to Omaha (via Sioux Falls)	369	MPE
		Omaha to Kansas City	168	MPE
		Bismarck to Sioux Falls	315	MPE
(9)	National Air Line System	St. Petersburg to Jacksonville (via Daytona Beach)	237	MPE
(10)	National Airways, Inc.	Boston to Bar Harbor	253	MPE
		Boston to Burlington	193	MPE
(11)	National Parks Airways, Inc.	Salt Lake City to Great Falls	489	MPE
(12)	North American Aviation, Inc. (Eastern Air Lines Division)	New York to New Orleans (via Atlanta)	1296	MPE
		New York to Miami (via Charleston, S.C.)	1144	MPE
		Chicago to Miami (via Jacksonvil e, Louisville and Nashville)	1267	MPE
(13)	Northwest Airlines, Inc.	Chicago to St. Paul (via Rochester)	356	MPE
		Chicago to Pembina (via Milwaukee)	769	MPE
		Fargo to Seattle	1267	MPE
		Pembina to Winnipeg	65	PE
(14)	Pan American Airways, Inc.	Miami to Havana	229	MPE
		Miami to San Juan	1180	MPE
		San Juan to Paramaribo	1378	MPE
		Paramaribo to Buenos Aires	4840	MPE
		Miami to Cristobal (via San Salvador)	2228	MPE
		Miami to Cristobal (via Kingston and Barranquilla)	1810	MPE
		Barranquilla to Port of Spain	1021	MPE
		Miami to Nassau	188	MPE
		Tampa to Havana	339	PE
		Brownsville to Mexico City (via Tampico)	496	MPE
		Mexico City to San Salvador	951	MPE
		Kingston to Port au Prince	304	PE
		Port au Prince to Santo Domingo	161	PE
		Belem (Para) to Manaos	852	PE
		Vera Cruz to Merida	530	PE
(14a)	Pan American Airways, Inc. (Aerovias Centrales)	Los Angeles to Mexico City	1684	PE
		El Paso to Durango	663	PE
(15)	Pan American-Grace Airways, Inc.	Cristobal, Canal Zone to Montevideo, Uruguay (via Santiago, Chile)	4552	MPE
(16)	Pennsylvania Airlines & Transport, Inc.	Washington to Detroit	410	PE
		Detroit to Milwaukee	265	MPE
(17)	Seattle-Victoria Air Mail, Inc.	Seattle to Victoria	74	M
(18)	Transcontinental & Western Air, Inc.	New York to Los Angeles (via Chicago, Kansas City and Amarillo)	2583	PE
		New York to Los Angeles (via Columbus, Indianapolis and Kansas City)	2555	MPE
(19)	United Air Lines Transport Corp.	New York to San Francisco (via Chicago)	2647	MPE
		San Diego to Seattle	1161	MPE
		Agua Caliente to San Diego	14	PE
		Seattle to Vancouver	119	PE
		Salt Lake City to Seattle (via Portland)	816	MPE
		Pendleton to Spokane	169	MPE
(20)	Varney Air Transport, Inc.	Pueblo to El Paso	519	MPE
(21)	Watertown Airways, Inc.	St. Paul to Spearfish	559	PE
(22)	Wedell-Williams Air Service Corporation	Houston to New Orleans	329	MPE
(23)	Western Air Express Corp.	San Diego to Salt Lake City	702	MPE
(24)	Wilmington Catalina Airline, Ltd.	Wilmington to Avalon	31	PE
(25)	Wyoming Air Service, Inc.	Cheyenne to Pueblo	199	MPE
		Billings to Cheyenne	380	MPE

M—Mail. P—Passenger. E—Express.

Between 1927 and 1933 generous mail contracts helped to place the principal airway operators in a sound financial position. Early in 1934 all domestic air mail contracts were suddenly cancelled and for three months no air mail revenue was obtained. When the contract system was renewed the prices were materially reduced and many companies have since been operating with a deficit. The serious effect of this reduction is shown in the following returns, from the two largest operators. American Airlines showed an operating loss of $888,504 in 1934 and United Airlines a loss of $2,283,525. Economies in operation and the increase of other revenue has now restored the position in large measure, as in the first nine months of 1935 American Airways' deficit has been reduced to less than $400,000, while United Airlines show a profit for the quarter ending 30th September of $304,565.

Pan American Airways System

With the exception of the Canadian connections at Montreal, Winnipeg and Victoria, the foreign air operations under the United States flag are conducted by Pan American Airways and its associated companies. Beginning in 1928 with a single route—Key West to Havana—251 miles long, its route mileage today is about 45,000 miles. In 1929 the terminal was moved to Miami and a series of extensions commenced, which, by 1931, served the West Indies Islands, Mexico and all Central American Republics, the Panama Canal zone and both coasts of South America as far south as Buenos Aires and Santiago.

In 1932 the local Alaskan services were unified in Pacific Alaska Airways, a subsidiary company, and in 1933 49 per cent of the capital stock of Chinese National Airways was acquired, giving the company access to important centres in the Far East. These were extended in 1934 and in 1935 the trans-Pacific service—San Francisco, Honolulu, Midway, Wake, Guam, Manila—was successfully inaugurated. This trans-Pacific service will be extended to New Zealand in the near future. An agreement was reached in November, 1935, with that government providing for a regular service from Honolulu to Auckland, New Zealand. This will give New Zealand and Australia direct connection by air with the United States and Canada. When the trans-Atlantic services are inaugurated a girdle will have been thrown completely round the world by Imperial and Pan American Airways. The summer of 1936 will see the aircraft of both companies co-operating in experimental trans-Atlantic air services through agreements reached in Ottawa and Washington last November.

Pan American Airways is certainly second to no company in the world in the efficiency and thoroughness of its organization. Its record speaks for itself. Its plans are carefully matured and its safety and reliability are proverbial. Its aircraft are the finest available and its ground organization of the highest type.

These results have been made possible by the timely assistance of the United States government through mail contracts at generous rates and in other ways. The company's operations have been profitable. In 1932 the company is stated to have had a net income of $512,581 and in 1933 of $631,640 or earnings per share of $1.36 and $1.42 respectively.

Canada

Canada played an important part in the early experimental stages of aviation through the efforts of Dr. Graham Bell and his associates. The scene of their activities was Baddeck, Cape Breton, and the first flights in the British Empire were made from the ice there by Messrs. Baldwin and McCurdy on February 23rd, 1909. There was little flying in Canada, however, before the war.

During the war there was great activity in training pilots for the overseas forces and several large training camps were established in Ontario, while thousands of young Canadian transferred from active service units overseas to the Air Forces, both Naval and Military. All these activities were, however, directly under the United Kingdom government and no distinctively Canadian units were established until immediately prior to the armistice. These units were demobilized after the armistice and Canada entered the post-war period with no air organization, either military or civil.

The important part aviation could play in the development of the Dominion was recognized, however, and in 1919 the Air Board Act was passed establishing a Board for the administration of aeronautics. Air Regulations based on the International Convention for Air Navigation became law on January 1st, 1920, and orderly development was, therefore, possible from the outset. This country was far removed from the rivalries which have interfered with economic development in Europe and elsewhere and the problem could thus be considered strictly on its merits. Enquiries were made with a view to determining where aircraft could be used to the best advantage. In our vast northern areas better means of transport were urgently required. It was to this field that our aims and energy were directed after the war. There aircraft could play an immediately useful part in work of the greatest importance to the Dominion.

Experimental work in forest patrols was begun in August, 1919, at Grand'Mere through the co-operation of the Provincial Forest Service, one of the large pulp and paper companies, and the Dominion government. The success attending these experiments quickly led to the establishment of air units for forest fire patrol, mapping and exploration work, in conjunction with the provinces of British Columbia, Ontario, and Quebec, and the Dominion Forest Service in Manitoba, Saskatchewan and Alberta.

The surveyor, geologist, and prospector were not slow to follow the example of the forester and use aircraft as a better means of transportation and observation throughout the unsettled areas of Canada.

The result of this policy has been that today there exist generally throughout northern Canada efficient commercial air services which have been self-sustaining, have required no subsidy, and which give access to the remotest districts of the country. More has been learned of northern Canada during the past ten years than in the preceding three hundred. The forester, surveyor, geologist, prospector, mining engineer; the clergy, the doctors, the nurses, the police; in fact, all whose activities lie in northern Canada find their task greatly lightened, their range of action multiplied many times and their efficiency increased

Statistics Operations of Pan American Airways

	1928	1929	1930	1931	1932	1933	1934
Airway route mileage	251	12,265	17,861	20,664	26,652	30,982	32,552
Aeroplanes	7	64	98	102	107	124	139
Radio weather	—	—	—	—	—	—	—
Stations	3	25	44	51	59	94	99
Personnel	118	987	1,593	1,667	1,918	2,292	2,801
Passenger miles flown	297,000	5,360,000	8,980,000	12,479,000	19,571,000	27,511,000	35,000,000
Mail and express carried	270,155	485,140	731,187	819,657	1,279,130	1,562,361	1,884,000

by the use of aircraft. Journeys which a few years ago meant weeks or months, and sometimes even years of toil and hardship, are now performed in ease and comfort in a few hours. The expansion of Canada's mining industry has greatly helped to tide Canada over the dark days of the depression and this development has been immensely assisted and hastened by aviation. Many of our most promising new mining fields owe their discovery and their opportunity of present development entirely to aircraft. The extent of this development is shown in the following statistics:—

	1930	1931	1932	1933	1934
Aircraft miles	7,547,420	7,046,276	4,569,131	4,538,315	6,497,637
Flights	156,574	144,080	102,219	106,252	128,031
Hours	92,993	73,645	56,170	53,299	75,871
Passengers	124,875	100,128	76,800	85,006	105,306
Passenger miles	5,408,676	4,073,552	2,869,799	3,816,862	6,266,475
Freight and express (pounds)	1,759,259	2,372,467	3,129,974	4,205,901	14,441,179
Mail (pounds)	474,199	470,461	413,687	539,358	625,040

(In 1935 the poundage of mail carried will exceed 1,125,000.)

	1930	1931	1932	1933	1934
Private air pilots	311	292	356	405	427
Commercial air pilots	402	366	419	474	405
Air engineers	370	346	341	403	461
Private aircraft	48	66	45	49	38
Commercial aircraft	445	495	303	296	330
Air harbours	70	78	91	105	101

The best proof of the soundness of our northern services is their continuation throughout the depression without any form of subsidy. Canadian development is unique in this respect. No country has spent less on civil aviation and no country has had greater returns from the money spent. The results achieved are due wholly to the enterprise and efficiency of the private operator, who has expanded his activities throughout the length and breadth of northern Canada and today is providing efficient service through all parts of the north. Operating conditions are strenuous, the work is carried on summer and winter with only short intermissions during the freeze-up and break-up periods in fall and spring. The single-engined general purpose monoplane is the most popular type. Flying is on floats in summer and skis in winter and the average pay load is about 1,200 pounds.

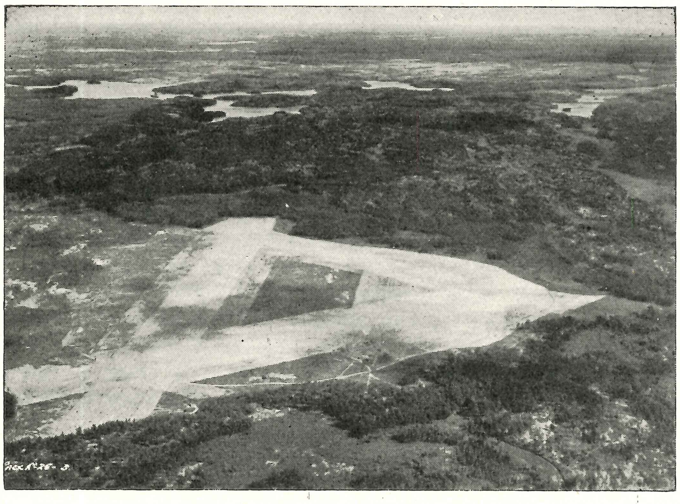


Fig. 11—Intermediate Landing Field at Caddy Lake, Man.

The development of inter-city services was not ignored but enquiry in 1920 had shown that in the circumstances existing in the early post-war years there was no immediate necessity for the inauguration of such services. The cost would be great and the physical difficulties of winter flying had not yet been overcome. In addition, the war type aircraft were not particularly suited to this class of work nor was public opinion ripe. It was decided, therefore, that an inter-city system could well wait for some years.

In 1927, however, it was realized that the time had come when Canada could no longer neglect this field and surveys were then commenced to determine the best route for the trans-Canada airway. In Europe, a complete airway system had been organized and the United States' services were beginning to tap Canadian traffic at strategic points along the frontier. The danger that through these points of contact high speed traffic now passing through Canadian channels might be diverted southward to the United States was clearly realized. By 1929 construction on the trans-Canada airway was sufficiently far advanced to permit of a daylight service from Windsor to Moncton in the east and a night service between Edmonton, Calgary and Winnipeg in the west. This latter airway was lighted for night flying and was equipped with the latest radio beam and communication services. At the same time, surveys through the difficult mountain section enabling the Prairie system to be extended to the Pacific coast were in hand, while the problem of bridging northern Ontario, which two generations before had presented immense difficulties to the railroad constructor, was being carefully examined.

This was the situation when the financial crisis made economies in all government services essential. The operation of the airway ceased, for the time being, on March 31st, 1932. Fortunately, construction work has been continued as a measure of unemployment relief. The airway through the mountain section has been practically completed, while much work has been done in the northern Ontario section, and in Quebec, New Brunswick and Nova Scotia so as to complete the system from Vancouver to Halifax.

The trans-Canada airway crosses the Rocky Mountains from Vancouver by the Crow's Nest Pass to Lethbridge. Exhaustive surveys have shown that this route is not only the shortest and most direct, but is preferable from a climatic and flying point of view. It also serves a more densely populated area in which several airports had already been constructed. From Lethbridge a north and south branch has been built to serve Calgary and Edmonton as well as the main line to Regina and Winnipeg.

The path chosen from Winnipeg through northern Ontario follows approximately the line of the National Transcontinental Railway as far as Cochrane, whence it passes south-east to Emsdale, dividing there for Toronto to the south and Montreal to the east. From Montreal the airway continues through the eastern townships of Quebec, the state of Maine and New Brunswick to Moncton with connections to Halifax, Charlottetown and Sydney.

The trans-Canada airway is a co-operative effort in which the municipalities served have provided a chain of twenty-one airports from coast to coast. The extent to which they have contributed in this way is often forgotten. Not less than $4,000,000 has been spent on such airports. The aids to air navigation on the airway, such as intermediate aerodromes, airway lighting, meteorological and radio services have been constructed by the Dominion government following the precedent of marine navigation.

The Prairie section, which was built in 1929 and 1930, includes twenty-seven intermediate fields, fifty-nine airway beacons and five radio beam stations. The Mountain, Central and Maritime sections now under construction comprise a total of sixty-six intermediate aerodromes, of which five are completed and nineteen are so far advanced that their use in daylight is now possible. Construction

has commenced on twenty-six others and the sites for an additional ten are under option or have been purchased, leaving six still to be purchased.

The most serious effect of the stoppage of scheduled airway flying in March, 1932, is not the delay in construction and operation but the loss of experience in modern airway operation. Progress in this phase of flying operations has been extraordinarily rapid during the past four years and a highly skilled and experienced personnel, both air and ground, is essential to the successful operation and co-ordination of the flying, meteorology, radio and communication services. Such services cannot be improvised in a day but must be built up gradually over a period of years. The opportunities for so doing are entirely absent in Canada today and our personnel, who have shown a natural aptitude in aviation since its beginning, are without the facilities to keep them in touch with modern flying practice.

The trans-Canada airway is not only of value as a national project, but is an important part of the airway system of the world, which has been assuming shape during the past few years. As has been seen, all continents are now spanned by airways over which a constantly increasing stream of traffic is passing. This country is one of the great trading nations of the world and we only maintain this position and our high standard of living because of our external trade. The means of communication which serve this trade are, therefore, of great concern to Canada. The shortest routes from the North American continent to both Europe and Asia lie through Canadian territory. The transatlantic and transpacific airways are, therefore, of vital importance to us. These routes, together with the trans-Canada airway, are the three great links still awaiting organization in the world airway system.

The Trans-Atlantic Airway

Recent conversations in Ottawa between representatives of the United Kingdom, the Irish Free State, Newfoundland and Canada, and subsequently in Washington with the United States authorities, foreshadow the early development of a transatlantic service. The North Atlantic is the greatest trade route in the world and on it, if anywhere, will be found traffic of sufficient volume, urgency and value to justify the addition to the present highly organized means of transport and communication of an express service for mails, passengers and freight by air.

Three transatlantic routes have received much attention of recent years; the northern route, via Baffin Land, Greenland and Iceland; the direct route, via Newfoundland and the Irish Free State; and the southern route, via Bermuda and the Azores. The direct interest of Canada in the first two is manifest and careful study of conditions on both have been made for many years. The inaccessibility during the greater part of the year of the bases on the northern route and the inhospitable climate have led to the conclusion that the northern route is not a practical one under present conditions. In addition, while it provides a short route from points in eastern Europe, such as Berlin, Leningrad and Scandinavia, to western Canada and the United States, it does not provide a direct or short route from London and Paris to Montreal and New York. Attention has, therefore, been directed to the establishment of a service by the direct route. As a preliminary step the first regular air mail service in Canada was established in 1927 from Montreal to Rimouski to hasten the delivery of outgoing and incoming transatlantic mail. This ship-to-shore service has been operated successfully during the summer season of navigation since that date without the loss or damage of a single packet of the many millions carried. In 1930 and 1932 experimental flights were made with a view to further expediting the mail by making the transfer from the ship to the aircraft in the Straits of Belle Isle and so making one-third of the trans-Atlantic passage by air.

The increase in the range, speed and carrying capacity of aircraft now makes it possible to consider an all air service across the Atlantic, and experimental flights may be expected during 1936 by Imperial Airways and Pan American Airways, who are co-operating in the establishment of the service with the support of the British Commonwealth governments concerned and the United States. The operating difficulties on this route are obvious. High westerly winds, fog on the Atlantic coast and the prevalence of critical temperatures which lead to ice formation on the planes, render it, perhaps, the most arduous of the world's airways. Only a resolute and determined effort, using the highest type of equipment and a thorough ground organization will suffice to master the difficulties. Sufficient is known, however, of the conditions to justify confidence that in a very few years the regular operation of a trans-Atlantic service by this route will be feasible during the summer months at least.

On the southern route the climate is better, and though the route is much longer, yet the operating difficulties are less and for some years it is probable that, just as trans-Atlantic liners use northern and southern courses during the summer and winter months, the trans-Atlantic air service may pass by alternative routes.

Comparison of Trans-Atlantic Air Routes

Distance	Arctic	Direct	Southern
From London, England to			
Montreal	4357	3330	5767
New York	4687	3660	5437
Number of intermediate bases	8	2	4 (to Lisbon)

The Trans-Pacific Airway

A trans-Pacific route has now been established by Pan American Airways from San Francisco via Honolulu, Midway, Wake and Guam Islands, to Manila, there connecting with existing and proposed airways in the Far East. This route is much longer than the direct route, which revives the old question of "the north west passage" to China. The great circle course from Chicago to Shanghai passes through Winnipeg, Chippewyan, Simpson, Dawson, Fairbanks and Nome, Alaska, thence across the Bering Straits by a short sea passage of only a few miles, and down the coasts of eastern Siberia, Manchuria and China. That part of this airway which lies on the American continent is well known and a large part of it is regularly flown over in both summer and in winter by northern operators. Present information justifies the statement that its operation is feasible and that a service from Edmonton via the Peace, Liard and Yukon river valleys, which all lie adjacent to the direct line of flight, could be operated with ease and safety. Political conditions in the Far East, however, have militated against its consideration up to the present and until more settled conditions prevail there it is unlikely that any active steps will be taken to develop this route. Its great advantage is that stops for refuelling can be made at economic intervals, whereas on the longer sea route via Honolulu the pay load is bound to be restricted by the long distances which must be traversed without refuelling.

It will thus be seen that Canada's northern position on the American continent is most important to the world's airway system and that the trans-Canada airway is a vital link between the Old World and the New.

This brief and incomplete survey of the world's airway

system shows that during the depression, in a time of falling trade and traffic returns, aviation has not only held its own but grown by leaps and bounds. No country, except Canada, has materially reduced its expenditures on civil aviation during the past five years, but, on the contrary, expansion has been rapid and widespread. The world's airway system is the growth of the last six years and the only remaining major links still to be developed are in Canada or pass through her territory.

Aeronautical science is still young and the future will see great progress in the design of aircraft for long distance services at still higher speeds and with greater economy. The present generation is witnessing a shrinkage of the world similar to that which followed the introduction of the railway and steamship. Distance is best measured by the time taken to traverse it. Instantaneous communication is today possible throughout the civilized world by radio and cable. Tomorrow, personal contact throughout the world will be possible by air transport with little loss of time.

The philosopher may ask—Why all this speed? and the economist may question its cost. Such questions apply equally to the radio and telephone, the automobile and, in fact, to all appurtenances of our modern civilization. Fortunately for our Institute and its members, man is not a wholly reasonable or economic animal. The desire for achievement, imagination, the exercise of ingenuity, the love of invention, gifts of particular interest to engineers, play an important part in his being and motives. Quite apart from its very real practical uses in the modern world, aviation appeals to these higher qualities in man. The past ten years have witnessed a generous and enthusiastic outpouring of them in aeronautical science unparalleled in the history of mechanical invention. Its first fruits are our present airway system, thrown round the world in a few short years.

High Altitude or Stratosphere Flying

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Paper presented before the Aeronautical Section of the Ottawa Branch of The Engineering Institute of Canada, February 20th, 1936.

SUMMARY:—The possibilities of high-altitude flying will depend on many factors, the characteristics of the atmosphere, the design of the aircraft, the engine, its cooling, air supply and fuel, the airscrew and other considerations which are concisely discussed in this paper.

All scientific men like a challenging problem, and for this reason the problem of flying in the stratosphere has attracted world-wide attention from aeronautical scientists. This problem owes its fascination not only to the immediate economy that it promises in long distance and high speed transportation, but to the fact that when it is being considered numberless features appear under a new aspect, each one of which challenges the ingenuity of the designer.

A number of papers have been written on this subject, and references will be given to many of these. The only excuse for the presentation of another paper is that up to the present no writer has attempted to outline the chief points which confront the designer when he starts to consider the stratosphere aeroplane, and, therefore, a collection of a large number of these queries, which must of necessity be still very incomplete, should be of some value to others when they are confronted with this problem for the first time.

In many instances reference will be made to matters which are well known to aircraft designers, and this has been done purposely so that those readers who are not closely connected with the design of aircraft can appreciate the points raised and perhaps give the assistance of their own specialized knowledge towards the solution of a common problem—the conquest of the elements.

The Atmosphere

The atmosphere consists of a mixture of gases in nearly constant proportions for normal altitudes, and with varying amounts of water vapour.

Near the earth these gases are subject to continual changes in velocity both horizontally and vertically, and, therefore, the properties, such as pressure, density and temperature, vary considerably with time, with the result that, for the purpose of standardizing our methods of calculation, it is necessary to adopt average values for these properties. This has been done by the adoption of what is known as the "International Standard Atmosphere." Since the adoption of this standard it appears as though designers and operators have lost sight of the fact that the atmosphere usually departs widely from standard conditions.

Mr. Glaisher's record of temperatures during a balloon flight on April 6th, 1864, illustrates this point, and shows that wide ranges of temperature occur during even a short flight. (See Fig. 1.)

Composition of the Atmosphere

The average composition of the atmosphere at sea level is nearly ⅕ oxygen and ⅘ nitrogen, with small quantities of other gases and water vapour in varying quantities.

It was at one time thought that the composition varied greatly with altitude, but Gay-Lussac in 1804 obtained samples of air from a height of about 23,000 feet, and determined that the composition was practically the same as at the sea-level. It is known now that the oxygen proportion remains constant up to about 45,000 feet and then begins to fall off slightly. At about 270,000 feet there is probably no oxygen.

The hydrogen content becomes appreciable from 150,000 feet, and at very great height there is reason to believe that the atmosphere consists largely of pure hydrogen.* (See Fig. 2).

It should be noticed that at a certain height the hydrogen and oxygen will be present in the proportions of 2 to 1.

Air Temperature

The temperature at the surface of the earth varies widely with location and season. The extremes of temperature recorded are 133.3 degrees F. in the Sahara and −94.5 degrees F. in Siberia. Air temperatures at heights have been recorded, and it is found that on the average the temperature decreases steadily with height at a rate of approximately 3 degrees F. per 1,000 feet up to a height of about 35,000 feet, in temperate zones, above which the temperature remains almost constant, for some considerable height. The standard atmosphere assumes that the absolute temperature (T) varies with height in kilometres (h) according to the formula

$$T = 288 - 6.5\,h$$

These values are plotted in Fig. 3.†

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*Wood's "Technical Aerodynamics," McGraw-Hill, New York.
†"Handbook of Aeronautics," Gale and Golden Ltd., London.

At the equator the fall in temperature with height continues to greater heights, before a nearly constant temperature is reached, with the result that the constant temperature at height over the equator is lower than that over the temperate regions.

Various writers have different opinions upon the variations in temperature at great heights, but obviously the number of observations must be so small that they are useless for obtaining average values.

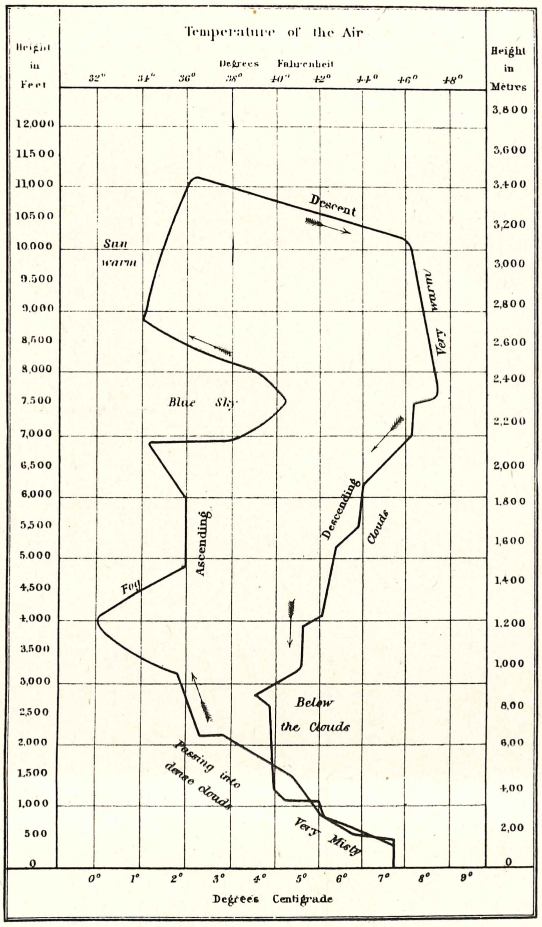

Fig. 1—Temperature of Air at Different Heights observed in Ascent and Descent, 1864.

Air Pressure

The air pressure is determined by the weight of the column of air above the point under consideration. It is seen, therefore, that the pressure must decrease with height.

The law used for the standard atmosphere is

$$\frac{p^0}{p} = \left(\frac{288}{288 - 6.5\,h}\right)^{5.256}$$

where h is in kilometres and the standard sea-level pressure is 760 m.m. of mercury (see Fig. 3). The pressure at the ground and at heights is variable as is well known from the continual variations of the barometer.

Air Density

The air density varies in a similar manner to the pressure, and can be calculated from the values of temperature and pressure, by using the formula $\rho = \frac{p}{RT}$.

The values for the standard atmosphere are plotted in Fig. 3.

The Stratosphere

It has been shown that at a height of about 35,000 feet in the temperate zone the temperature of the atmosphere ceases to fall with height. That portion of the atmosphere below this height is called the "troposphere," whilst the portion above this height is called the "stratosphere." The dividing line is called the "tropopause," and its height above sea-level varies from about 50,000 feet at the equator to 35,000 feet in the temperate zone, and probably much less nearer the poles.*

Clouds

Clouds may consist of either water or ice particles held in suspension by rising currents, therefore, at heights at which there is no water vapour there can be no clouds.

Clouds exist up to about 30,000 feet, and will certainly not be met with in the stratosphere.

Winds in the Stratosphere

Some writers have discussed the probability of the existence of strong winds prevailing at the height of the stratosphere with velocities as high as 120 m.p.h. from the west to east. These winds if they actually existed would have a bearing upon the height at which it was economical to fly, particularly when it was desired to travel towards the west.

The author has been unable to find any authoritative source which would confirm the existence of such prevailing winds, and in fact the evidence so far collected indicates very little wind at great heights.

It is well known that winds increase in strength as the height above the ground increases, but on the other hand the evidence collected from the flights of stratosphere balloons and from the observation of pilot balloons does not reveal the presence of any very formidable wind, but these balloon flights and observations have, of course, been made under good weather conditions.

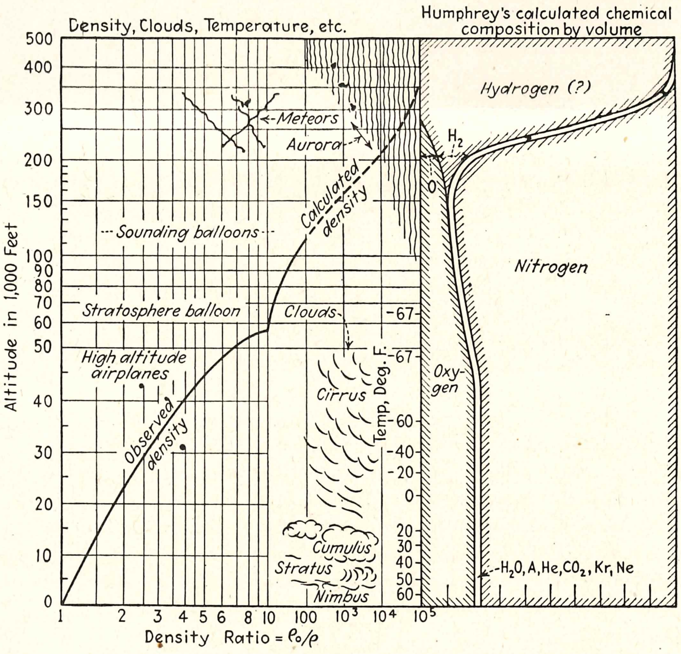

Fig. 2—Calculated Chemical Composition of Atmosphere by Volume.

In Captain Stevens' flight of July 28th, 1934,† the wind recorded at 40,000 feet was S.E. 55.7 m.p.h., and at 60,000 feet was S.W. 10 m.p.h. Also the stratosphere flight in the balloon "Explorer II" of November 11th, 1935,‡ indicates a total drift of 225 miles in eight hours thirteen minutes, of which one and a half hours was at approximately 70,000 feet; the details are not yet available. Similarly, results

*"Travel in the Stratosphere" by G. T. R. Hill, Journal of Royal Society of Arts, December 20th, 1935.

†National Geographic Magazine, October, 1934.

‡National Geographic Magazine, January, 1936.

obtained, from the Meteorological Office in Toronto, by observers of pilot balloons in Canada indicate that under the fair weather conditions when the pilot balloon can be seen at great heights, the wind speed rarely exceeds 50 m.p.h. with one or two notable exceptions, e.g., Victoria, B.C., May 5th, 1933, 12,000 metres, wind 123 m.p.h. S.S.E., Belle Isle Newfoundland February 20th, 1931, 10,000 metres, wind 79 m.p.h. W.S.W.

The Human Machine

The human machine like the internal combustion engine needs both fuel and oxygen, but in addition demands that the oxygen shall be served up in a manner suitable to its needs.

Adaptability to Conditions

Air at sea-level contains about 20 per cent of oxygen at a pressure of nearly 15 pounds per square inch, and both the engine and the human machine are normally suited to working under these conditions.

As the height above sea-level increases the pressure and density of the air decrease, and the power given out by an internal combustion engine also decreases in a similar manner, but the human machine is less accommodating.

It has been found that if the human machine is not required to perform much work it can accommodate itself to a height of 15,000 feet without any serious inconvenience. At this height the pressure has been reduced to nearly one half (0.55) of its sea-level value. If given time the human machine can adapt itself much more fully to the new conditions by actual changes in the blood. A quick rise to 20,000 feet may cause fainting due to failure of the oxygen to reach the blood. The pressure is then about 0.45 of sea-level pressure. Greater heights can be reached if the quantity of the oxygen in the air is increased artificially, and by this means a height of about 35,000 feet can be reached when the pressure is about 0.2 of sea-level pressure.

It appears, therefore, as though the human machine is satisfied with air containing $\frac{1}{5}$ oxygen at sea-level pressure, or with pure oxygen at $\frac{1}{5}$ sea-level pressure, which resolves itself into the statement that it requires an equivalent oxygen pressure of $\frac{1}{5}$ sea-level pressure.

Just as it is possible for a height of 15,000 feet to be reached within the range of accommodation available when using air, so is it possible by using oxygen to reach 42,000 feet, provided that no work is to be done, and the fainting height for pure oxygen is at about 46,000 feet.

Donati, a well trained altitude pilot, reached a height of 47,360 feet using oxygen with some CO_2, and landed in a state of collapse, indicating that he had reached the limit for the apparatus available.

Above these heights it becomes necessary to supply air, or oxygen, under pressure, but as a human being cannot stand even a small internal pressure, the pressure must be applied externally at the same time.

Respiratory System

The air contained in the lungs (alveolar air) under normal conditions has the following composition:

	CO_2	N_2	O_2	H_2O
Per cent	5.3	74.1	14.4	6.2

The oxygen, therefore, contributes about $^1/_7$ of the air pressure within the lung spaces, or alveoli.

The red pigment in the corpuscles of the blood has the power of taking up, or giving off, oxygen with increase or decrease in pressure with a maximum richness of oxygen when the oxygen pressure is about $^1/_7$th atmospheric.

The pressure of the oxygen in the lungs causes the oxygen to diffuse through the light membranes into the blood contained in the capillaries in the walls of the alveoli. The oxygen is carried by the blood to the tissues where it is to be used, and when the oxygen is given up to those tissues the blood automatically picks up the waste product CO_2 and carries it back to the lungs. When the CO_2 laden blood reaches the lungs, the CO_2 diffuses through the membranes into the alveoli at the same time that oxygen is entering the blood.

The diffusion of oxygen in one direction and CO_2 in the opposite direction is due to the fact that the partial

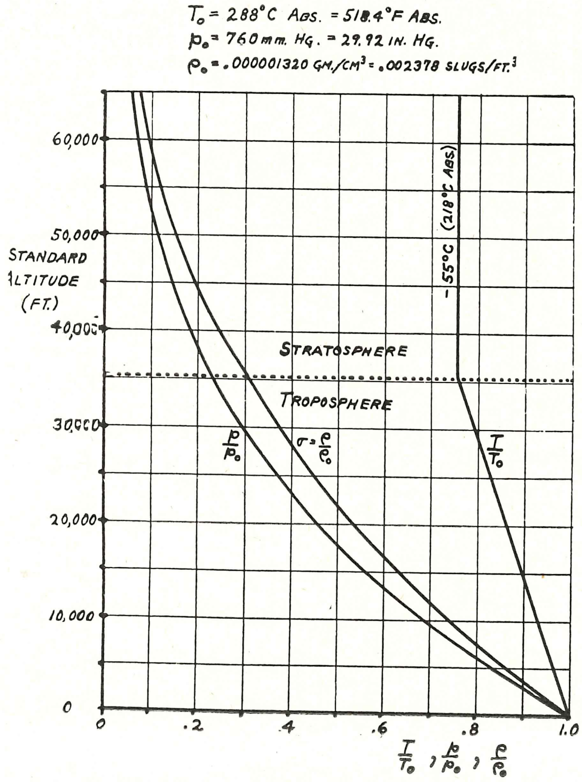

Fig. 3—Properties of the International Standard Atmosphere.

pressures due to these gases are different on the two sides of the membrane. With a high oxygen pressure in the alveoli, and a low oxygen pressure in the returning blood, oxygen passes into the blood; similarly with a high CO_2 pressure in the returning blood, and a low CO_2 pressure in the alveoli the CO_2 will pass from the blood into the alveoli.

Also the more work that is done by the tissues the more the used blood is robbed of oxygen and charged with CO_2, resulting in increased oxygen supply to the blood, and the necessity for greater breathing action to keep up the oxygen pressure in the alveoli.

The presence of CO_2 in the air that is to be inhaled is also of importance, because it appears to act as a stimulus for breathing action, and it is interesting to note that Donati actually used a small proportion of CO_2.

Anoxœmia (Oxygen starvation)

We have seen previously that although the proportion of oxygen in the air remains practically constant up to great heights, the pressure diminishes rapidly. The result of this diminution of pressure is that the oxygen pressure available in the lungs is not sufficient to saturate the blood with oxygen, and a lower percentage of oxygen is absorbed by the red pigment in the blood as can be seen by a change in the colour of the blood from red towards the blue.

If the change takes place slowly the blood can adapt itself within limits to the new conditions by increasing the number of red corpuscles, and even have an increased chemical affinity for oxygen due to change in chemical composition.

air against the pressure existing at the discharge side. If the blower is not required to give full output it is only necessary to open a valve on the discharge side, thus reducing the pressure that is built up in that region, with consequent reduction in the power required to drive the blower.

With a supercharger built on this principle the losses of power at low altitudes can be much less than with the geared type supercharger, but it is less economical in fuel than other types, and is unwieldy.

It is probable that superchargers of this type with suitable coolers, and even with tandem superchargers, could be constructed to suit the requirements of stratosphere flying, if more attractive methods of doing the same thing were not available.

The Exhaust Driven Supercharger

With this type of supercharger a centrifugal fan wheel similar to that used for the geared supercharger is driven by a turbine, which uses the exhaust gases escaping from the cylinders.

By arranging a by-pass it is possible to allow only the required amount of the exhaust gases to pass through the turbine, and thus the work done by the supercharger can be regulated to that actually required at all heights up to that at which the supercharger is giving its maximum output.

The fact that the power for the drive comes from the exhaust gases allows considerable economy, because the engine output is only called upon to the small extent resulting from the slightly greater back pressure on the exhaust valves.

Theoretically the power available for driving the supercharger increases with height, due to the fact that the exhaust pressure remains nearly constant, whereas the pressure of the air is reducing with height. Actually the problem is more complicated, because the speed of the turbine wheel coupled with the high temperature of the blades causes difficulties in construction, which become much worse as the height range is extended. Also the high temperatures resulting from the compression of the air make the air quite unsuitable for use in the engine until it has been cooled. This means that a two-stage supercharger would be necessary with a cooler between the stages, and between the second stage and the engine. This problem is difficult, but by no means impossible.

Another possible arrangement is that in which the engine is provided with a geared type supercharger suitable for moderate heights, and in addition with a Root's type, or exhaust driven type of supercharger with intercooler, for providing the additional supercharging required.

Engine Cooling

The air density being lower at altitudes, and the temperature also being lower, these two factors act in opposite directions upon the transmission of heat from a heated surface to the surrounding air. Increase in speed assists the cooling, provided that the speed does not approach the velocity of sound. At the stratosphere there is no further lowering of temperature, and in fact it may increase with greater heights, and then the loss in density becomes the deciding feature.

Crocco has estimated that for any given set of conditions, such as the temperature of the surface to be cooled, height, etc., there is a most efficient speed for cooling, above which the cooling falls rapidly.* When the speed approaches the velocity of sound it becomes impossible to consider the use of the internal combustion engine, at any rate in its present form, because it cannot be cooled by systems at present in use. The cooling of the engine must, therefore, be studied along the lines outlined by Crocco, in order to determine to what extent the cooling surface of the cylinders must be increased to suit the conditions likely to be encountered.

Magnetos and Insulation

The distance across which a spark will jump between two metal spheres, maintained at a constant difference of potential varies in rough proportion with the density of the surrounding air. If, therefore, it is contemplated operating in air at a density of 1/5 sea level density, then the distances across which sparks will jump will be increased by approximately five times.

The design of magneto parts, particularly distributors may under these conditions offer some difficulty, and screened spark plugs, as at present used, may need redesigning by bringing the insulation right over the terminal on the end of the plug, if this does not introduce plug cooling difficulties.

All the electrical installation will need to be considered from this point of view, and the use of coil-ignition may prove of some assistance.

Fuel

The vapour pressure of the fuel employed at present is usually about 7 pounds per square inch at 37.8 degrees C., and, therefore, evaporation of fuel may take place if great heights are reached before the fuel has cooled sufficiently to decrease its vapour pressure materially, and unless arrangements are made to maintain the pressure in the fuel tanks.

The most suitable method of overcoming this would probably be to seal the tanks and to connect them to the supercharger outlet, so that they are kept at sea level pressure, with the supercharger supplying the air necessary to replace the volume of fuel consumed. Under these conditions the tanks will be subjected to considerable internal pressure at heights, which must be provided for in the design. The freezing point of the fuel is around −50 degrees C., a temperature which will certainly be reached by the atmospheric air, necessitating the retention of sufficient heat in the space surrounding the fuel tanks. This should not be difficult because the problem of getting rid of heat in the supercharger coolers, and the engine cooling should make ample supply of heat available for this and similar purposes.

Ozone Effect

It has been shown that the presence of a very small percentage of ozone in the air supplied to an engine will cause an appreciable decrease in the apparent octane value of the fuel being used. This may be a serious question because the engines will be working at sea-level power at altitudes, due to supercharging, and the full octane value of the fuel will be required.

The amount of ozone in the atmosphere is not known very definitely, but the stratosphere flight by the balloon "Explorer II" of November 11th, 1935, may give some interesting information on this point, as it is known that air samples from above 60,000 feet were obtained on that flight.

It is considered possible, however, that ozone exists in appreciable quantities in the Heaviside layer, at heights of about 130,000 feet during the day, and there may, therefore, also be appreciable quantities at the heights now being considered.

Batteries

The stratosphere balloon "Explorer II" was surrounded by mist, when at the top of its flight, due it is assumed, to evaporation from the batteries, which were slung outside the gondola.

With an aeroplane flying at great heights the batteries would probably be kept quite warm, and serious evapora-

*Technical Memorandum 690, National Advisory Committee for Aeronautics, Washington, 1932.

The effects of oxygen starvation are vividly described by Glaisher, who noticed particularly that the first symptom was loss of power of the hands. The effects are diminution of judgment, drowsiness, breathlessness and muscular weakness, followed by a gradual loss of power over the members, starting with the hands, and finally unconsciousness.

Amount of air required

The discomfort experienced in a crowded room is not due to the increase in the carbon dioxide as much as the

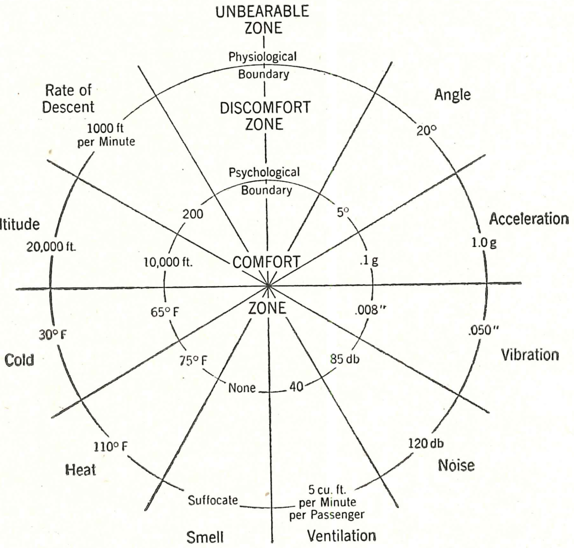

Fig. 4—Passenger Comfort Chart.

fact that the body becomes surrounded by moisture laden air, and relief can be obtained by circulating the air without actually changing it. Also air containing as much as 5 per cent of carbon dioxide can be breathed without distress.

It has been found, however, that more cubic feet of air per passenger are needed in aeroplanes than in other forms of transportation. Studies of passenger comfort indicate a requirement of 30 cubic feet of air per minute per passenger, with a possible range of from 40 cubic feet per minute down to a minimum, which would be accompanied by discomfort, of perhaps 5 cubic feet per minute.*

Angle of Tilt

The angle of tilt also has to be considered, and it has been found that whereas 5 degree change is comfortable 20 degree change is unbearable, and, therefore, with rapid climbs and glides it may be necessary to provide some means of changing the position of the seats.

Rate of Climb

From experience gained with transport aircraft it has been found that the rate of climb must be limited to a figure of about 200 feet a minute, in order that the passengers can adapt themselves to changing pressures. Any higher rates of climb, or descent, cause inconvenience. It has also been found that with "sleeper planes" changes of height cannot be made while the passengers are asleep, because they do not swallow sufficiently, and consequently suffer from the change of pressure.

The Internal Combustion Engine

Power Variation with Altitude

The power given out by an internal combustion engine depends directly upon the weight of oxygen entering the cylinders, other conditions remaining constant. Therefore, as an engine is taken to greater heights the power will fall off almost in direct proportion to the fall in density of the air, but it is important to note that unlike the human machine there is no upper limit, and the internal combustion engine will continue to give power even at very low air densities.

In order that the engine can be usefully employed at heights it is necessary to provide some method by which the power given out at heights can be maintained at a value which is commensurate with its weight.

Methods of Maintaining Power at Heights

Various methods have been suggested for maintaining the power of aero engines at heights, but the method now generally adopted is the use of a supercharger. The supercharger consists of an apparatus, which will compress the air from the free atmospheric pressure to some predetermined figure usually taken as sea-level pressure, and maintain this predetermined pressure up to some predetermined height. Under these conditions the engine output will be approximately constant up to the predetermined height, but some of the output will be absorbed in driving the supercharger itself.†

The Geared Supercharger

This is the type most generally used at the present time. It consists of a centrifugal fan driven by gearing from the engine crankshaft, and discharging into a diffuser, which is part of the induction system of the engine. This type of supercharger involves a high power loss at low altitudes, because it is necessary to throttle the engine considerably, in order to keep down the induction manifold pressures to figures that can be handled without engine troubles.

For this reason geared superchargers have not usually been constructed for maintaining sea level pressure at heights greater than 15,000-20,000 feet.

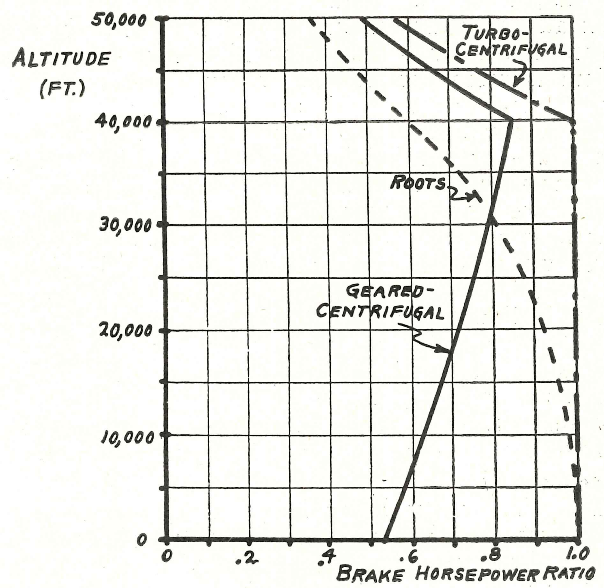

Fig. 5—Net Brake Horsepower of various Types of Supercharged Engines of 40,000 ft. Critical Altitude. (Based on data from N.A.C.A. T.R. No. 384.) Specific Fuel Consumption Ratio at 40,000 ft. critical altitude; Turbo = 1.00. Geared Centrifugal = 1.18. Roots = 1.69.

In order to fly in the stratosphere one must contemplate maintaining sea level power at 30,000-40,000 feet. It is possible to consider the use of a gear driven supercharger, in which there is incorporated a change speed gear, so that at low levels the fan wheel can be run more slowly, and the amount of throttling thus reduced.

The Root's Type Supercharger

In this supercharger a rotary blower of the Root's type draws in air at the suction pressure, and forces this

*"Passenger Comfort in Air Transportation," by G. R. Bassett, Journal of Aeronautical Sciences, March 1935.

†"High Altitude Flying," by W. B. Oswald, Journal of Aeronautical Sciences, January, 1935.

tion might occur if they were not carried inside the pressure compartment.

The Aircraft

In considering the aircraft requirements it is desirable to investigate the most difficult type, in order to bring out as many as possible of the questions that require attention. It is proposed, therefore, to consider a passenger carrying aeroplane with capacity for about twenty passengers.

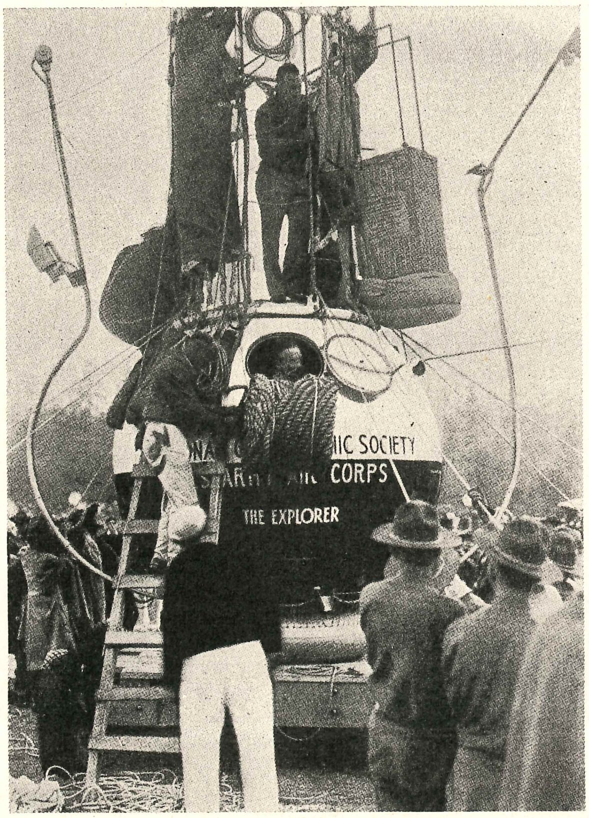

Fig. 6—Gondola of "Explorer I."

Actually the difficulties can be greatly reduced by considering a mail carrying aeroplane with a crew of two, because the problem of looking after the requirements of two men for a journey of nearly eight hours in the stratosphere has already been solved for the stratosphere balloons. It would, therefore, only be necessary to follow the experience already gained by building into the fuselage a spherical cockpit equipped with air-conditioning apparatus similar to that used for the balloons. The weight of the structure of the gondola of the balloon "Explorer I" was about 700 pounds* (see Fig. 6).

Effect of Change of Fineness and Loading

The performance characteristics of an aeroplane can be represented by a curve, such as *A* in Fig. 7, in which the ordinates represent the horsepower required, and the abscissæ represent the forward speed. Curve "*A*" represents the characteristics of an aeroplane of 1913, which had a top speed of about 72 m.p.h., and a landing speed of about 42 m.p.h.

By calculating the total resistance at top speed the relation of this to the total weight gives a measure of the efficiency or gliding angle. In the example considered, the gliding angle at top speed is 1 in 5.5. If the same aircraft is supplied with a more powerful engine, without changing other features, the speed is increased, but at the expense of the gliding angle. For instance, by increasing the horsepower available per 1,000 pounds from 36 to 48 the speed is increased from 72 m.p.h. to 80 m.p.h., but the gliding angle is reduced to 1 in 4.4. The top speed can be still further increased by increasing the wing loading, and, therefore, the landing speed.

Curve "*B*" shows a typical performance curve for an aircraft of military type in 1932. In this aircraft the stalling speed is now 65 m.p.h., and the top speed is 170 m.p.h., but the best gliding angle is no better than that of the 1913 aeroplane, and the gliding angle at top speed is only 1 in 4.2 showing that performance has been obtained by increase in power rather than by improvement in the aerodynamic properties of the aeroplane. Curve "*C*" gives the performance of a modern transport aeroplane of clean design, in which increase in wing loading is accompanied by the use of flaps to keep the landing speed down, and in which the best gliding angle approaches the figure 1 in 16. This aeroplane at a top speed of 196 m.p.h. has a gliding angle of 1 in 7.6, which is almost as great as the best gliding angle for the aeroplane of curve *B*, and the top speed is obtained at an effective horsepower per 1,000 pounds of 68 as compared with 109 for the previous aeroplane.

This comparison indicates the enormous advantages to be obtained from clean design.

Effect of Altitude upon Aeroplane Performance

In any aeroplane flying at a constant angle of attack

$$W = \frac{\rho}{g} \cdot K_L \cdot AV^2 \qquad (1)$$

$$HP = \frac{\rho}{g} \cdot K_R \cdot \frac{AV^3}{550} \qquad (2)$$

with W, K_y, K_D, A and g constant.

ρV^2 is constant from equation (1) and for a given angle of attack V will vary as $\frac{1}{\sqrt{\rho}}$

Also from equation (2)

HP will vary as ρV^3, i.e. as V for ρV^2 is constant

i.e. HP will also vary as $\frac{1}{\sqrt{\rho}}$

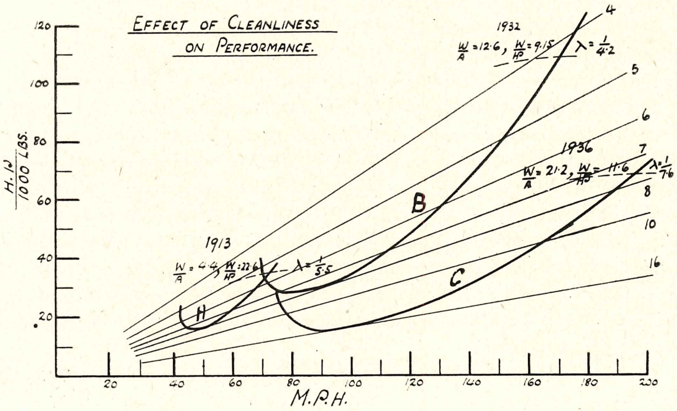

Fig. 7—Effect of Cleanliness on Performance.

In order to determine the effect of altitude it is, therefore, only necessary to increase the ordinates and abscissæ of the curves for performance in the proportion of $\frac{1}{\sqrt{\rho}}$. This has been done in Fig. 8 for a large passenger carrying aeroplane of good aerodynamic efficiency.

At sea level with an effective horsepower of 2,400 the top speed is 180 m.p.h., and the gliding angle at this speed is 1 in 6.

*The National Geographical Magazine, October, 1934.

If the horsepower available is kept constant without increase in weight up to about 22,000 feet with $\rho = .5$, then the top speed becomes 227 m.p.h., and the gliding angle at top speed is 1 in 7.6.

Similarly at 40,000 feet with $\rho = .25$ the top speed becomes 292 m.p.h. and the gliding angle 1 in 9.6.

So that for each decrease in ρ or increase in height at which the horsepower can be maintained constant there is a corresponding increase in top speed and in efficiency up to the maximum when the aeroplane is flying at its best gliding angle, which occurs at the point D on the figure.

This indicates that at heights of about 50,000 feet, if the engine power can be maintained, the speed can be increased by about 100 per cent over the sea level figure. The pay load will, however, be reduced by the increase in weight necessitated by flying high, i.e., superchargers, etc., which may be compensated for by the reduction in fuel needed for a given journey.

There is another interesting way of regarding this question, and that is by supposing that it is desired to fly at constant speed at sea level top speed figure of 180 m.p.h., then the curves A and B indicate that by flying at 22,000 feet, this same speed can be obtained by using only 1,200 h.p. instead of 2,400 h.p. as required at sea level.

The fuel required for a given journey depends upon the horsepower and the time, i.e., the fuel consumption for a given journey depends upon the horsepower required divided by the speed, and if the horsepower remains constant the fuel required is decreased proportionally to the increase in speed, with allowance made, of course, for climbing to the desired height. Considerable economy can, therefore, be made by flying at great heights for long distances when the fuel consumed in climbing to the height becomes a small proportion of the whole, and is partially offset by the fact that at the end of the journey during the glide little fuel is consumed.

Speed Limitations

From what has gone before it must not be assumed that the speed of an aircraft can be increased indefinitely. The reason for this is that at high speeds, approaching the velocity of sound, the compressibility of air becomes important, and the characteristics of an aeroplane wing section may be considerably changed.

This problem has not yet been fully investigated, but tests on models at speeds up to the speed of sound indicate that at about .7 of the speed of sound the lift of an aerofoil at a given angle of attack may be considerably decreased and the drag increased. When flying at great altitudes and low temperatures the speed of sound is reduced (see page 335) and the speed of the aircraft may approach the conditions under which the change in the characteristics of the wing takes place. It has been found, however, that these changes vary a good deal with changes in the shape of the wing section, and it may be possible to obtain a wing section which will be suitable for use at speeds well beyond the range required.

It should be remembered that the Reynolds number will be low, due to the low air density, in spite of the greater speeds and lower viscosity of the air.

Refinements in Aerodynamic Features

It is important to remember that the full benefit of high altitude flying can only be obtained by using aircraft of high aerodynamic efficiency. Therefore, every refinement such as high aspect ratio, tapered wings, flaps, retractable undercarriage, etc., must be employed.

Cabin Design

In the first instance consideration will be given to the problems that arise in the design of a cabin to carry passengers at great heights.

To provide for the requirements of the personnel the cabin must be supercharged, and it is necessary to decide upon the pressure difference that must be provided for in the design.

The human machine works quite satisfactorily up to heights of about 15,000 feet where the pressure is 0.55 of sea level pressure. Therefore, the internal pressure of the cabin need not be kept above this, or perhaps a slightly

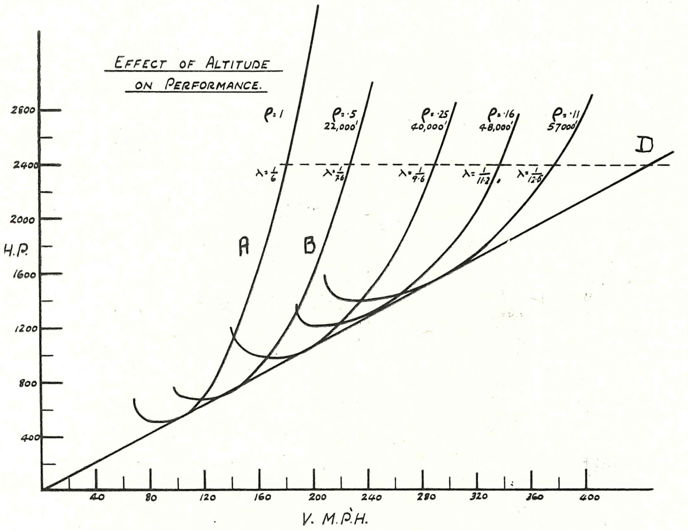

Fig. 8—Effect of Altitude on Performance.

higher pressure, say, 0.7 of sea level pressure (10,000 feet). If the maximum height to be employed is 50,000 feet, then the minimum external pressure will be about 0.12, and the difference between internal and external pressure will be (.7 − .12) p or 8.6 pounds per square inch. This figure could be still further reduced if the oxygen content was maintained higher than normal by the evaporation of stored liquid oxygen.

There are, however, many objections to maintaining the pressure at anything below the sea level pressure, the chief one being that if the cabin is to be kept open to the air until a height of say 13,000 feet is reached, then the climb to that height has to be done very slowly, in order to avoid discomfort to the personnel.

It is, therefore, advisable to seal the cabin at ground-level and design to a maximum difference of pressure of $(1 - 0.12) \times 14.7$ or 13 pounds per square inch. This figure must be multiplied by a factor of safety of at least 2½ for design purposes, giving a design figure of 32½ pounds per square inch.

Assuming that the usual monocoque construction will be used and that the cabin will be circular in section with a diameter of about 7 feet the thickness required will be found to be only slightly greater than is at present employed for similar structures. The internal pressure puts the whole skin in initial tension, and the loads applied to the fuselage as a whole apply additional compression and tension loads, so that the effect of the internal pressure is to reduce the compression loads which usually determine the size of members to be used.

It is essential that the cabin shall not suddenly develop leaks, and the usual single row riveted joints are not likely to be suitable, because of the liability of the plate opening up between the rivets, therefore, the joints must have two or three rows of rivets.

The usual type of construction employs longitudinals of extruded section, which are supported at the transverse frames of the fuselage. If the frames are stiff, then the longitudinals will bow between the frames, giving the out-

side a corrugated appearance when the cabin is under pressure.*

It has been suggested that to overcome this, it might be desirable to employ flexible frames which would expand under pressure, and allow the longitudinals to take up a continuous curve.

The tail end of the fuselage will not be under pressure, and, therefore, there will be a discontinuity in the structure where the tail end joins on to the pressure cabin, which must be allowed for in the design of the longitudinals.

The frames must be true circles because any change in radius means large bending moments and increased stresses.

To provide the most economical bulkheads they should be of hemispheric shape. This is easy at the rear end of the cabin, but more difficult if it is desired to provide a pressure bulkhead between the pilot's cockpit and the passengers. This latter point will be referred to again.

Floors must be independent of the walls of the pressure cabin, because a large flat surface carrying pressure cannot be designed economically. The pressure compartment must, therefore, extend out to the circular shell, and the floor supported inside, but not made air-tight.

When under pressure the cabin will increase both in length and diameter involving some complications in the neighbourhood of port holes and doors. Also the attachment of the fuselage to the wing, which will not expand, needs special provision for this relative movement.

The high internal pressures make it necessary for the doors and windows (or perhaps port holes) to open inwards so that the pressure can be employed to hold them against rubber rings to keep them airtight.

The windows for the pilot offer the greatest difficulty for although when once well clear of the ground it would only be necessary for the pilot to have small port holes, the aircraft when operating near the ground must be provided with ample visibility for the pilot. This could perhaps be obtained by operating the aircraft up to say 15,000 feet, after which the pilot would close metal shutters over his windows and rely on small port holes in the shutters. The space between the shutter and the large windows would require to be put in communication with the atmosphere to avoid having difference in pressure on the two sides of the window.

Supercharging the Cabin—Up to the present it has been tentatively assumed that the cabin would be retained at sea-level pressure, mainly for operating reasons, which demand high rates of ascent and descent.

It has been stated already that in so far as the personnel are concerned the pressure could be much lower if the oxygen percentage was raised to compensate for the lower pressure. There are serious objections to using pure oxygen by reason of the great risk of fire, therefore, assuming once more that air at sea-level pressure is to be used, it becomes necessary to provide some form of supercharger somewhat similar to that required for the engine.

The best method of driving this supercharger would probably be by providing an auxiliary engine, which drives only the supercharger for the cabin and for its own requirements. The volume of air required by the personnel is comparatively small, i.e., 20 to 30 cubic feet per minute per person, but absolute reliability is necessary. To secure reliability it may be desirable to divide this supercharger unit into two, because the personnel can easily, if necessary, exist with a much reduced supply of air, provided the pressure is maintained, and particularly if the air is kept in circulation within the cabin, and under these emergency circumstances one supercharger would be ample.

*"Structural Features of Supercharged Cockpits and Cabins," by J. E. Lipp, Journal of Aeronautical Sciences, November, 1935.

The cabin supercharger would require intercoolers with a close adjustment of the temperature of the air entering the cabin.

Pressure Regulation—It would be necessary to adjust the air supply so that pulsations did not exceed the equivalent of ± 10 feet in height or ± .005 pounds per square inch, necessitating a very delicate automatic control. The supercharger would probably discharge through coolers into a reserve tank kept slightly above cabin pressure with a regulating valve admitting the air to the cabin. The outlet from the cabin would be by a similar regulating valve set at a pressure slightly below that used for the inlet valve, thus allowing the required quantity of air to pass through the cabin.†

The design of the outlet valve again requires special attention, because this valve must maintain a given pressure inside the cabin whatever the pressure may be on the outside. Actually this problem is not so formidable as it seems, because with a cabin attendant available it is possible to use a simple screw down valve adjusted from time to time to maintain the desired rate of flow, as indicated by a meter of the gas-meter type.

Emergency Equipment—In the event of failure of the supercharger, and especially if the duplicate supercharger units were not provided the first consideration would be to close off the outlet valve. This would be automatic if an automatic outlet valve was used. Then it would be necessary to draw upon an emergency supply of liquid air carried for the purpose. This liquid air would be evaporated to supply the minimum amount required, and the pressure kept down to normal by regulating the outlet valve. In the meantime the pilot would lose height as quickly as possible, necessitating perhaps twenty minutes before the cabin could be opened to the outside air at a height of 15,000 feet.

A loss of pressure from any cause is much more serious, but could be countered for a short period by carrying a supply of liquid oxygen, and enriching the oxygen content in the cabin as the pressure fell, always bearing in mind the risk from fire with very rich oxygen mixtures. It has been argued that in an emergency it is in the interest of the whole that the pilot should be given the last remaining air, and that for this reason the pilot's cockpit should be separated from the cabin by an airtight bulkhead. This would allow the pilot to shut off the air supply to the cabin, and use the last remaining air in his own cockpit, whilst he manœuvred the aeroplane to a height at which the cabin could be opened.

Alternatively, the pilot could be provided with a Wiley Post type suit (Fig. 9), or emergency oxygen apparatus, to achieve the same purpose. It is hardly likely to be popular for the passengers to be provided with suits of this type, or even for them to wear oxygen apparatus and thus avoid the structural difficulties in making a supercharger cabin.

Water Vapour and CO_2—The air given off from the lungs contains appreciable quantities of moisture and carbon dioxide, whereas the air drawn in at great height will be devoid of moisture, and contain very little carbon dioxide. It is probable that with a continual leak of air, the amount of CO_2 will not cause any difficulty, because the CO_2 content of the air may be allowed to rise to 5 per cent without trouble. The moisture may on the other hand become too high in spite of the dry air that is being supplied. In the stratosphere balloons, bags containing sodium hydroxide, over which the air was circulated by a fan, were used to keep the air in good condition, and some such device may be necessary.

†"Methods of Cabin Supercharging and Their Necessary Control Systems," by A. L. Klein, Journal of Aeronautical Sciences, November, 1935.

Cabin Insulation—The gondola of the last stratosphere balloon was painted white on top to reflect sunlight and black below to absorb heat from the earth. It was found that at the lowest outside temperature the temperature inside the gondola was 21 degrees F., and that at greater heights where the outside temperature was higher the inside rose to 43 degrees F. As indicated previously, there should be plenty of heat available from the intercoolers

Fig. 9—Suit for Stratosphere Flying.

for the superchargers, and consequently not much difficulty about keeping the cabin warm.

However, as the air temperature will be at least −50 degrees C. the metal skin of the fuselage will be much too cold to sit against, and some provision must be made for insulation to avoid the proximity of cold walls to the seats, and to reduce condensation of moisture on the cabin ceilings.

Insulating boards can easily be used for this purpose, but other proposals may appear more attractive.

If the cabin was provided with a double wall the space between the walls would be useful for cooling and storage space for the air from the cabin supercharger. In this event the outside wall would probably be the pressure wall, because there would be little difference of pressure between the cabin and the air storage space, and the inner wall could be very light. Leaks inwards are not a serious matter.

Controls and Instruments

Some designers who have investigated this problem foresee some difficulty in carrying the pilot's controls from inside a pressure cabin to the other parts of the aeroplane. Professor Piccard recently pointed out that by using a tube led into the side of his gondola with a rubber tube fitting over this tube and the rope passing through it, he was able to keep down the leakage to very low figures.

In any event there should be little difficulty in arranging for controls of any kind to pass through the walls of the cabin by suitable glands.*

*"High Altitude Problems," by M. E. Gluhareff, Journal of Aeronautical Sciences, March, 1926.

The altimeter is comparatively simple, depending as it does upon the expansion of a sylphon disc when subjected to reduced pressure, but it must be remembered that the altimeter case must be made airtight and connected to the outside of the cabin.

Another altimeter open to the cabin would be a suitable instrument for measuring cabin pressure.

The airspeed indicator measures the difference between the pressure and suction sides of the pitot head, and, therefore, will at great height be subjected to large corrections to take account of the lower density of the air. The important thing again is to ensure that the instrument case is airtight at the comparatively large pressure differences, which will occur between the inside and outside of the case when the cabin is under pressure. Also rubber connections will not be suitable because they will collapse under the cabin pressure, and are liable by failure to cause leaks from the cabin.

Load Factors

The aircraft will be designed to suit the operating conditions, and nothing unusual should be encountered, except that an economical flight path calls for high rates of descent. At these high rates of descent when the aeroplane reaches disturbed air, gusts become of great importance and must be provided for in the load factors.

De-icing Equipment

In order that the stratosphere aeroplane shall be able to enjoy the full advantages of its great operating height it is essential that it should be capable of reaching that height under really bad weather conditions near the ground.

The worst condition that will be encountered is probably an icing condition, and, therefore, the aeroplane must be provided with some form of de-icing equipment, which will allow it to climb for perhaps twenty minutes while reaching more suitable atmospheric conditions.

Any accumulation of ice will presumably be evaporated when once the aeroplane has reached atmospheric conditions of very low humidity. At 25,000 feet, for instance, the average moisture content of the air is reported to be less than 4 per cent of the average for sea level.

The Airscrew

The airscrew presents one of the most difficult problems to solve because it must be efficient under such widely different conditions. A continuously variable pitch airscrew is evidently necessary.

The airscrew top speed must not approach too closely to the velocity of sound in air, and this velocity decreases with decrease in temperature.

$$V_t = V_o \left(1 + \frac{\alpha t}{2}\right)$$

Where V_o is 33,060 cms./sec. at 0 degrees C.

t is in degrees C. and $\alpha = .00366$.

So that at $t = -55$ degrees C. the velocity of sound is decreased by about 10 per cent.

A rough estimation of the requirement for an airscrew for cruising at a height of about 48,000 feet indicates that the airscrew requirements dictate a larger diameter than would normally be used, and the limitation in tip speed indicates the necessity for low revolutions.

This leads to the use of a geared down airscrew of large diameter and four blades.

The requirements for an airscrew for climbing at intermediate heights can be met fairly well with the same airscrew as is required for cruising at heights, but as lower heights are considered the efficiency falls. Also the pitch changes necessary to meet the varying conditions are very great causing inefficiency, due to the unsuitability of the helix on the airscrew blade, but pitch changes of 30 degrees have already been used experimentally.

These considerations lead to the necessity for reducing the variations in $\frac{P}{D}$ and the most suitable method of doing this appears to be by using greater blade widths than are used at present.

The airscrew will be a compromise to meet greatly varying conditions, and in order to obtain efficiency at great heights it may be necessary to consider the use of a catapult for starting, or alternatively, a carrier-aeroplane of the Mayo type, in order to provide suitable take-off conditions.

The Flight Path

If the meteorological conditions that would be experienced at all heights over the proposed journey could be accurately forecast it would be possible to work out the most economical heights at which to fly, and also the most economical rates of climb and glide. These calculations would be based upon the known performance characteristics of the aircraft at all heights.

For a long flight, such as has been contemplated here it is improbable that anything beyond a general forecast of weather near the ground at the two ends of the journey will be available, and the flight path must be based upon general considerations.

If the passengers' cabin is to be open to the air up to 15,000 feet, then the rate of climb up to this height must be limited to about 200 feet per minute, occupying seventy-five minutes during which time the aircraft has travelled forward at a comparatively slow speed. This time is too long, and, therefore, the cabin should be sealed at ground level, and the aircraft can then be flown at greater rates of climb. It is probable that the best climbing speed for average conditions will be that at which the combination of propeller and aircraft gives the greatest rate of climb, thus allowing the aeroplane to reach its operating height in the shortest time. This applies particularly to bad weather conditions when it is obviously desirable to reach clear sky conditions as soon as possible.

It has been shown that the speed increases with height for constant horsepower, and, therefore, the theoretical economical height, other things being equal, would be that at which the supercharger equipment reached its maximum output. This statement must, however, be subject to the qualification that the actual economical height will also depend upon the characteristics of the supercharger-engine-propeller-specific fuel consumption combination, particularly when the engine is running at cruising speeds.

For short journeys this height may also be reduced, due to the loss of time in climbing.

A clean aeroplane fitted with a supercharger suitable for maintaining power to 40,000 feet will reach this height in such a short time that little is to be saved by reducing the height, and much can be gained from the increased speed at the greater heights.

When at its operating height the aeroplane could gradually descend with engines throttled in a long glide, but this is open to the objection that the aeroplane encounters the bad weather conditions which have been avoided by flying high. Therefore, it appears probable that the height should be maintained to a position from which the aeroplane can reach its destination with a given rate of descent. This rate of descent may be determined by the load factors employed in the design or by the question of allowable tilt.

Conclusion

At this stage one would be prepared to argue either for or against the possibility of realizing stratosphere flights within the next few years.

The various factors will be reviewed starting with those that appear to be unfavourable.

Unfavourable Factors

- (*a*) Difficulties of supercharger design and chances of cabin supercharger failure.
- (*b*) Difficulties of designing the cabin pressure and temperature regulators.
- (*c*) Difficulties of designing the airscrews.
- (*d*) Impossibility of making short flights.
- (*e*) Difficulty of designing the pilot's cockpit to give adequate view.
- (*f*) Decrease in pay load due to extra equipment to be carried.
- (*g*) Increased cost of equipment and maintenance.
- (*h*) Possibility of unfavourable winds when travelling towards the west.
- (*i*) Uncertainty of attaining the speeds predicted due to breakdown in the air flow.

Favourable Factors

- (*a*) Economy of fuel due to high speeds, and thus allowing for increased pay loads.
- (*b*) Greater speeds obtainable for a given power.
- (*c*) No ice, clouds or fog.
- (*d*) Clear skies for navigation, day and night.
- (*e*) No bumps.
- (*f*) Possibility of favourable winds when travelling towards the east, with little evidence of any high winds.
- (*g*) High speeds have already been realized near the ground, and, therefore, breakdown in air flow not probable within the speed range contemplated.
- (*h*) Greater safety and comfort.

Welding of Light Walled Tubing

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Paper presented before the Aeronautical Section of the Ottawa Branch of The Engineering Institute of Canada, April 30th, 1936.

SUMMARY:—A study of the flame welding processes in which an excess of acetylene creates a carburizing atmosphere so as to avoid the formation of oxide and consequent deleterious effect on the physical properties of the completed weld—a matter of great importance in thin-walled tubing.

Welding of light walled tubing has been widely used in aeroplanes. Most of the developments of welded tubular design have been in conjunction with aircraft. Recently it has found wider use in other transportation fields and has been used on passenger cars for light weight streamlined railroad coaches and in automobile design.

Welded tubular design has a high ratio of strength to weight, permitting greater payloads. Welded joints are highly efficient and rigid, and, at the same time, light in weight. This type of assembly permits great flexibility of design and is economical to fabricate and to maintain. It will probably be used more extensively in the future. In the meantime the aircraft industry provides the best history of the development of welded tubular construction and the best indication of trends in design and materials.

When metal first replaced wood in aircraft members, carbon steels were employed. These are still used, as represented by the S.A.E. 1025 steels or their equivalent. Joint design and welding technique for this material were thoroughly investigated both in the field and in the laboratory. As the industry developed, higher speeds were attained in aircraft and greater stresses resulted. In the search for lighter or stronger materials, alloy steels were introduced. S.A.E. 4130 and S.A.E. 4130x or their equivalents have been widely used.

There are a number of specifications written to cover carbon steels and chrome molybdenum steels in various industries, and particularly in the aircraft industry. The following table is representative of these steels. It will be of assistance in making a comparison of the physical properties of the chrome molybdenum and the carbon steels.

Chemical Composition

	Carbon	Manganese	Chromium	Molybdenum
S.A.E. 1025....	0.20—0.30	0.30—0.60	......	......
S.A.E. 4130x...	0.25—0.35	0.40—0.60	0.80—1.10	0.15—0.25

Physical Properties

	Minimum Tensile Strength Pounds per square inch	Elongation Per cent in two inches
S.A.E. 1025..............	55,000	22
S.A.E. 4130x normalized	*90,000—95,000	*5—15
Oil quenched, approximate tempering temperature Degrees F.		
1,100	125,000	11
900	150,000	9
800	175,000	7
600	200,000	5

*Light gauges—minimum ductility—maximum tensile strength.

Chrome molybdenum steels have physical properties quite different from those of carbon steels. This is most noticeable in the relative tensile strength and ductility. These alloy steels also offer greater possibilities of heat-treatment. The fact that they may be heat-treated and that they air-harden should be taken into consideration when welding. An explanation of some of the significant factors in welding and a comparison of welding procedures may indicate how this may best be done.

The simplest phenomenon which happens when steel is heated, as in welding, is expansion. At the same time the steel becomes increasingly soft, ductile and weak. This has the advantage that stresses are dissipated over a wide area. On the other hand, the low strength at high temperatures makes it necessary that the piece be free to move so that undue load is not placed on the hot steel.

As additional heat is applied, the temperature rises to the recalescent point. In plain carbon steels this is about 1,400 degrees F. The metallurgical changes which take place here have a very practical significance. The carbon, which at lower temperatures has existed as discrete particles of iron carbide mixed with pure iron, goes into solution in the iron and remains in solid solution at temperatures above this point. On cooling slowly through this temperature, the carbon is again precipitated or thrown out as iron carbide. More rapid cooling tends to retard the reaction and to retain the carbon in solution.

Recrystallization takes place at about the same temperature as recalescence. When heated much above the recalescence point, steel crystals tend to grow in size to an extent depending on the length of time at the temperature and the amount the temperature exceeds the recalescence point. The shorter the time that the steel is held above the recalescence point and the lower the temperature, the finer the crystals will be and the better the physical properties.

Steel reacts with oxygen at all temperatures as illustrated by rusting at ordinary temperatures and by the adherent oxide scale which is found on hot rolled or forged stock. When reheated, the carbon in the adjacent steel begins to react with the iron oxide. The oxide is reduced and the products of the reaction escape as a gas. Migration of carbon is rapid and decarbonization may be to a considerable depth. The reaction is accelerated as the steel becomes molten.

In oxy-acetylene welding, the surface of the base metal and the welding rod both become coated with iron oxide or scale while heating up to welding temperature. Further, the iron oxide has a lower melting point than steel and must be removed to secure a sound weld.

These physical, metallurgical and chemical factors in welding are becoming more significant with the wider use of alloy steels. They are of considerable importance in welding light walled chrome molybdenum tubing. The air-hardening qualities and resulting high tensile strength and reduced ductility indicate that more attention has to be given to expansion and contraction of the steel, and to making certain that undue stress is not placed on the metal while hot. Though molybdenum is present to inhibit grain growth, it is desirable to reduce the temperature and the time that the steel is held above the recalescence point to a minimum. Further, with thin walled tubing, decarburization of a very small portion of the wall thickness affects an appreciable percentage of the area of the cross section. To obtain efficient joints, the welding rod must have a tensile strength comparable to that of the chrome molybdenum tubing and it must react favourably to heat-treatment.

The first oxy-acetylene welding rods which gave good quality welds were low in carbon and contained a minimum of other elements. This was reflected in the welding technique used. To obtain adhesion between the added metal and the base metal, a considerable amount of the latter was melted to make sure the oxide was removed. To eliminate the iron oxide from the weld, the weld metal

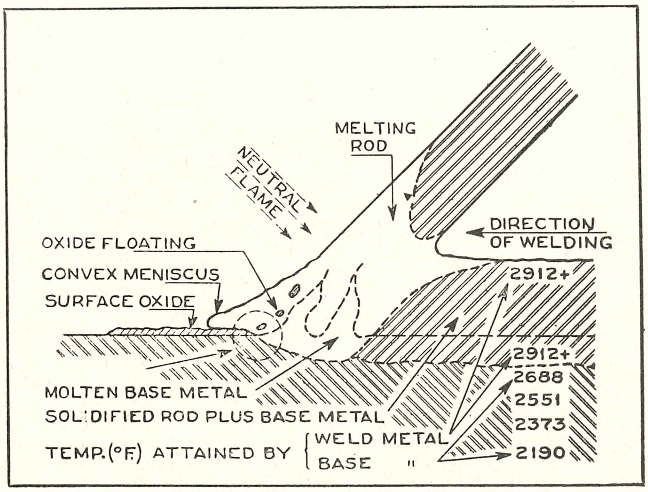

Fig. 1—Diagrammatic Sketch showing roughly what takes place during Neutral Flame Welding.

was heated well above melting temperature to obtain fluidity. As a result the weld was reduced in carbon and low in tensile strength as compared with the results obtainable today. The carbon content of the rod had to be low in order to avoid excessive reaction between it and the copious amounts of iron oxide that were present.

As the welding industry developed and knowledge of the needs and problems increased, new welding rods have been devised in which manganese and silicon have been added to reduce the iron oxide. With these, the products of the reaction are solids which form a fluid slag that floats to the top of the molten puddle. This effectively cleans the weld metal and protects it from further oxidation. The elimination of the carbon-iron oxide reaction in the weld makes it possible to increase the carbon content of this type of rod. Consequently the strength of the weld metal is increased and a sounder deposit is obtained. The active reducing agents readily remove the oxides, making excessive melting of the base metal or temperatures much above melting point unnecessary. The welding technique, however, is still very similar and a neutral flame adjustment is used.

Figure 1 illustrates the action of the welding puddle. The temperatures are representative of those obtained in a cross-section of a weld.

This type of welding rod and welding technique is widely used in the fabrication of tubular members. It is very satisfactory when used on straight carbon steels as with S.A.E. 1025 and good results are obtained with some chrome molybdenum steels, particularly if care is taken to allow for expansion stresses and heating held to a minimum to inhibit grain growth. A recent advance in welding procedure has further assisted in the welding of chrome molybdenum tubing.

This new process for oxy-acetylene welding utilizes certain distinct but co-operating properties of carbon and iron. The underlying principle of the process is comprised of the following relations; carbon is soluble in iron; carbon lowers the melting point of the mixture; this melting point is in the feasible welding temperature range; carbon reduces iron oxide; the non-metallic product of the reaction is gaseous and escapes.

If a piece of steel is heated to somewhat below welding temperature and is exposed to a carburizing influence, the surface layer of the white hot steel will absorb carbon and will spontaneously melt as the carbon approaches the eutectic mixture of 4½ per cent. This carbonaceous film does three things essential in welding. It prevents oxidation and reduces oxides. It promotes intimate contact by acting as a flux and causing the molten metal to run out over the melted surface. It acts as a temperature indicator denoting by its formation the proper time to add weld metal.

Fortunately from the standpoint of commercial feasibility, the carburizing agent is available in the standard oxy-acetylene welding equipment by proper adjustment and manipulation of the flame. As a weld progresses, carbon is absorbed to a depth of one or two thousandths of an inch on the surface of the steel and melts spontaneously. The blowpipe is manipulated so that the carbonaceous film covers the base metal adjacent to the welding puddle.

This film has certain unique features. It is metallic. It is produced automatically. It melts spontaneously, and it disappears by dissolving into the weld metal as soon as its functions are fulfilled. The action may be termed "self-fluxing."

The process known as Lindewelding is a typical example of this excess-acetylene welding. Figure 2 shows a weld being made using this process.

The flame high in acetylene coming from the tip (bottom of cut) melts the rod (top of cut), conditions the metal surface, and anneals the completed weld (not visible) behind rod.

Considered in terms of its application to welding on chrome molybdenum tubing, the process offers a number of advantages over the neutral flame method. It is faster. The indication of proper welding temperature by the spontaneous formation of the carbonaceous film permits more attention to be given to rod manipulation and the rod may be deposited more rapidly. Welding is carried on at a lower temperature.

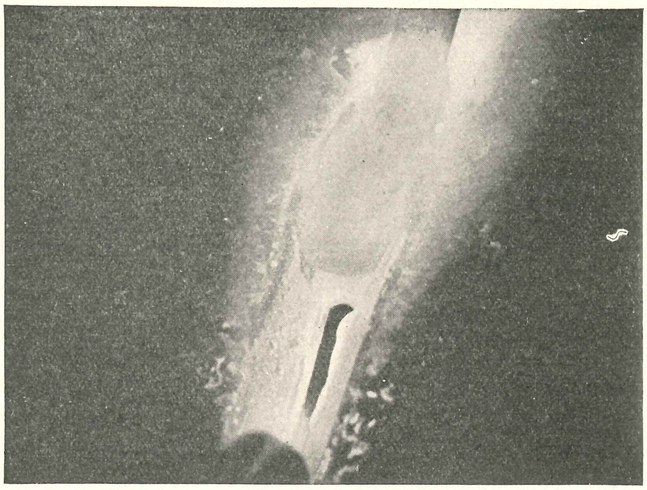

Fig. 2—A Weld in the Making.

Figure 3 shows representative temperatures of various sections of a weld using the excess-acetylene technique.

The combination of faster welding and welding at a lower temperature reduces the tendency towards grain

growth, as the time and the temperature at which the steel is held above the recalescence point are both reduced to a minimum. Reduced grain growth means improved physical properties.

The amount of expansion varies with the speed of welding. In general, the faster the weld the less the expansion that takes place, and the lower the resulting stresses. A backhand technique will result in slightly less expansion stresses than a forehand technique. The process thus assists in overcoming expansion and contraction problems.

The carburizing or reducing atmosphere properly controlled by the excess-acetylene type of flame tends to eliminate a decarburized surface on the tubing at the weld.

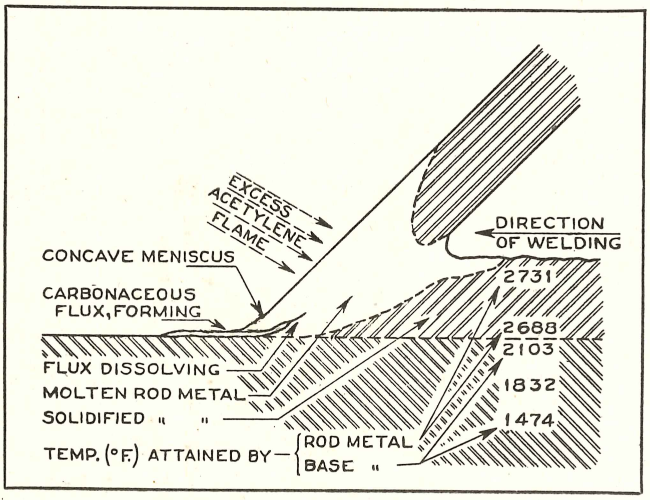

Fig. 3—Diagrammatic Sketch showing important points regarding Excess-acetylene Welding.

The external supply of carbon tends to maintain the carbon in equilibrium in the steel as it is not required to reduce the surface oxides. Carbon loss by migration is avoided.

This welding process reduces the probability of disturbing the chromium-manganese-carbon ratio of the steel immediately adjacent to the weld. The balanced composition proportioned to give optimum relationship between strength and ductility is maintained. Using a suitable rod and this technique, physical properties may be obtained by heat-treatment equivalent to those of the original material. On fittings and small assemblies, heat-treatment is desirable with the chrome molybdenum steels. On larger assemblies it is often impracticable. In either case the process assists in obtaining better welds.

One other item may be mentioned. Due to the semi-automatic features of the process it may be used readily with either a forehand or backhand technique. The physical properties of chromium molybdenum tubing in the normalized condition vary somewhat. Very light walled tubing tends to cool rapidly and with the air-hardening properties of the steel, a higher tensile strength and lower ductility is obtained. A backhand technique may be utilized to reduce the quenching effect where it is desirable to do so.

In the discussion which followed, the author supplied additional information of interest.

An inexperienced man may be trained to use the new procedure more quickly than neutral flame welding.

A welder may become proficient in a few days' practice on test pieces.

The author believes that on light gauge tubing the process described has not been used extensively in Canada up to the present, although many use a modified technique. When used on S.A.E. 4130x better physical properties are obtained than with the previous methods. This is due to the reduction of grain growth and of carbon loss.

The practice of heating the joint with the oxy-acetylene blowpipe after welding is for the purpose only of relieving internal stresses. Full heat-treatment is a more precise operation.

In the actual Lindeweld procedure:—

A tip one size larger than shown on blowpipe manufacturer's standard charts may usually be used by experienced operators.

A special alloy steel welding rod is used.

The excess-acetylene flame is not usually more than one and a half times the length of the inner cone when welding on light wall tubing.

The blowpipe is inclined to form a very acute angle with the seam being welded.

When the carbonaceous film is formed, which causes the metal to flow over the melted surface, the weld metal is added.

The blowpipe is manipulated so that the carbonaceous films covers the base metal in advance of the welding puddle.

The backhand method should be used for gauges under 16 (.065) and is preferable for larger gauges. The forehand technique may be used satisfactorily on the larger gauges.

While neutral flame welding may be used on S.A.E. 4130 the same reactions take place as in S.A.E. 4130x, though not necessarily to the same degree. Therefore excess-acetylene welding is preferable on S.A.E. 4130.

Similarly, when welding S.A.E. 1025 to S.A.E. 4130, it is advisable to use the technique and rod applicable to the greater strength member.

The heat effect from welding will be evident to a distance as much as ⅞ inch from the weld in proportion to the gauge, i.e. ⅞ inch for very heavy aircraft tubes.

Trends in Aviation Lighting in the United States

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An address based on this paper was presented before the Ottawa Branch of The Engineering Institute of Canada, September 4th, 1936.

SUMMARY.—Two U.S. Department of Commerce specifications covering the installation and performance of airport lighting equipment are analyzed. The requirements for the more important items of equipment are outlined, novel methods of specification are pointed out and departures from standards previously considered satisfactory in the United States are emphasized.

Introduction

Among the projects which the Congress has authorized to be carried out with W.P.A. funds is the improvement of airports, including their lighting. This authorization made government funds available for the purchase of considerable quantities of airport lighting equipment and made it necessary to prepare as complete specifications as the urgent demand for their immediate use would permit.

The Airport Section of the Bureau of Air Commerce was given the responsibility for the preparation of these specifications and assigned the task successively to three members of its staff. Mr. A. P. Seeley began the work, Mr. Paul Morris carried on through the thick of it, and Mr. H. J. C. Pearson brought it to a useful conclusion. With all three it was the writer's privilege to collaborate. Throughout the work, the authors of the specifications have profited by the constructive criticism of the illuminating engineers of practically all the companies that are actively engaged in building aviation lighting equipment in this country.

It was evident that the specifications must meet three tests. They must contribute as fully as possible to the safety of air transportation. They must stimulate and not impede the art of aviation lighting. They must deal equitably with all makers of aviation lighting equipment.

To meet these tests it was felt that the specifications should be drafted more broadly than is generally customary for purchase specifications, that the requirements should be strictly limited to performance requirements with no more limitations on the means of attaining the performance than reliability and efficiency require. It also seemed proper to utilize generally accepted specifications such as the Federal Specifications, the specifications of the Air Navigation Division, and the Underwriters' requirements.

In another respect the specifications are unusual. It has been necessary to design them for unusually flexible application. In some cases they may be used for a blanket contract covering the furnishing and installation of a complete airport lighting system ready for use. In other cases they may be used for the purchase of one or two items of equipment with no services at all furnished, all the labour being provided by the W.P.A. In still other cases it may be desired to contract for certain items of equipment and for the technical supervision necessary for its installation by W.P.A. workers. The specifications have been designed to serve in any of these circumstances.

Organization of the Specifications

At the time of the writer's first contact with these specifications, their general plan had already been adopted. In accordance with that plan they were to be developed under two titles: (1) "Standard Specifications for the Installation of Airport Lighting Equipment and Materials" and (2) "Performance Specifications for Airport Lighting Equipment and Materials." The installation specification is intended for the use of the various airport sponsors who are equipping airports with the aid of W.P.A. funds. The performance specification is a basic specification containing technical requirements with which the airport sponsors need not be personally familiar. In view of the intended use, the titles are not altogether happy selections since it is impossible to eliminate all performance requirements from the installation specification and it is essential to include many testing requirements in the performance specification.

The first part of the installation specification, about one-fifth of the whole subject matter, relates to general requirements. Following the general requirements are the specific requirements for the various types of lighting equipment. The last third of the specification is devoted to requirements for wiring and wiring devices.

The performance specification contains three general sections and seven sections devoted to specific types of lighting equipment. Of the general sections the first sets forth definitions of contractual terms; the second gives the definitions of the aviation colours together with requirements for testing the colours of lighting equipment; the third section gives the definitions of technical terms used in specifying the performance of equipment, and also instructions for photometric measurements. The types of equipment covered in the two specifications are listed below:

Rotating airport beacon	Wind cone
Intermediate airport beacon	Wind tee
Airport code beacon	Automatic control of lighting
Code beacon flasher	Landing-area floodlight system
Beacon tower	Ceiling projector
Boundary-light units	Alidade
Boundary-light circuit	Clinometer
Obstruction-light units	Parabolic hangar floodlights
Field-approach lights	Fresnel hangar floodlights
Contact lights	

In many cases it was found advisable to include in the specifications material intended primarily as information for airport sponsors. An outstanding case of this is Section 19 of the installation specification which is devoted to recommendations regarding the selection of equipment to meet the needs of various types of airports.

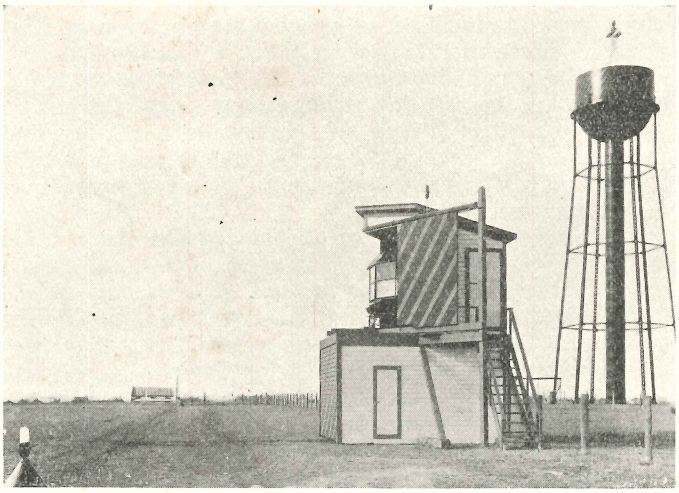
The preparation of the specifications led to several innovations in the manner of specifying the various types of equipment, and these are discussed in the remaining sections of this paper.

Airport Beacons

To specify an airport beacon by its performance and, at the same time, not to specify any particular model of beacon, presented a problem. Obviously two beacons having beams of the same maximum candlepower, but of different divergence, will not be equally visible under all conditions. On the other hand, to require a specified divergence, stated as a certain percentage of the maximum candlepower, places a penalty on a high maximum candlepower. To obtain a characteristic which is more representative of the actual visibility of a beam, the concept of "integrated horizontal intensity" has been introduced. This is defined as "the integral, or summation, of the area under the curve showing the horizontal candlepower distribution taken between the angles on either side of the axis of the

*"The Airport Lighting Specifications of the Department of Commerce," paper presented by Dr. Breckenridge before the thirtieth annual convention of the Illuminating Engineering Society, Buffalo, N.Y., August 31st to September 3rd, 1936. Publication approved jointly by the directors of the Bureau of Air Commerce and the National Bureau of Standards, Department of Commerce.

beam at which the candlepower first drops to 10 per cent of the specified axial candlepower." The candlepower distribution curve is to be drawn in rectangular co-ordinates and the unit area is that represented by a rectangle, the height of which corresponds to one candle, and the width of which corresponds to one degree. The combination of requirements setting minimum values for the axial intensity and for the integrated horizontal intensity insures a beam that is adequately powerful at its maximum and contains



Courtesy of Canadian General Electric Co.

Fig. 1.—Lethbridge, Alta. Airport, showing Boundary Lights, Revolving Beacon and Floodlight.

a sufficient cross section of luminous flux to give a good signal.

It has been found convenient to make a differentiation between beam spread and divergence. The beam spread has been defined in the usual manner to include the diverging light on both sides of the axis of a beam. The divergence, on the other hand, has been defined as an angle on one side of the axis only. It is believed that this differentiation between beam spread and divergence would be found a very convenient one if it were generally adopted.

The intermediate airport beacons constitute a new category set up to cover a recently-developed type which seems to have real merits for certain applications. These beacons, by virtue of their long flashes and high angles of vertical divergence, are especially adapted for visibility at relatively short distances in bad weather. They approach more nearly to the British theory of aviation beacons than any beacon previously developed in this country.

The requirements for codes flashed by airport code-beacons introduce a change in the relative lengths of some of the code elements. These requirements are based upon some unpublished experimental work done by Mr. J. A. Bartelt at the National Bureau of Standards several years ago. This work indicated that for the 500-watt lamp commonly used in those beacons, a period of 0.3 second is necessary to allow the lamp to reach approximately its full candlepower. The experiments also showed that it is very difficult for the average observer to differentiate between eclipses which have durations in a 5:3 ratio. For this reason the eclipse between repetitions of the code signal has been specified as nine times the duration of the dot flash, instead of five times the duration of this element.

Boundary, Obstruction, and Other Marker Lights

Boundary-light practice in the United States presents an unfortunately and unnecessarily confused picture. Many types of lamps and glassware are being used. Some of the glassware is inherently inefficient, and some of it is rendered very inefficient through the use of wrong lamps. In general, little or no effort has been made to make the candlepower of the red and green units equal to that of the "clear" or "white" units. A conference was held with lamp manufacturers, and the lamps available for boundary-light use carefully considered. As a result of this conference the requirements for boundary lights have been based upon the use of four types of lamps—two for multiple circuits and two for series circuits. For multiple circuits a 15-watt general-service lamp without frosting and a 60-watt traffic signal lamp have been selected. For series circuits a 320-lumen, 6.6-ampere lamp and a 1,000-lumen, 6.6-ampere lamp have been adopted as standard. The two multiple lamps have the same base and approximately the same light-centre length, and, similarly, the series lamps are interchangeable in these respects. This makes it unnecessary for any airport to have on hand more than one type of boundary-light fittings, and reduces by half or more the types of fittings which manufacturers must carry in stock. A similar simplification in practice has been brought about by adopting the threads heretofore used on series units as standard for both series and multiple units. This not only has the advantage of making the glassware interchangeable between series and multiple units, but also is more convenient for the airport mechanics as the threaded neck provided on the old multiple units was so small that it was not possible for the average mechanic to insert his hand into the glassware to clean it. The adoption by all airports of the standard lamps, and, as soon as feasible, of the standard fittings and glassware, is strongly recommended in the interests of efficiency. A comparison of the additional cost of refracting glassware for boundary lights with the cost of the additional electric power and copper to conduct it, which are necessary to make the non-refracting glassware as effective as the refracting glassware, convinced the Airport Section that efficiency dictates the use of refracting glassware for boundary and obstruction lights.

It is generally held that boundary-light circuits for large fields should be of the series type but that multiple circuits are more economical for small airports. In selecting lamps for the two types of circuits, it was found to be impracticable to obtain series lamps of as low wattage and light output as the multiple lamps which have been considered satisfactory. Since series circuits are generally used at the larger airports, which are likely to be located in metropolitan areas where competing highway lights add to the difficulty of finding an airport from the air, it seems reasonable that the series lamps should be of higher candlepower. In comparing costs based on the use of the recommended lamps, however, it must be borne in mind that the systems compared are not equally effective.

At the time Section 19 of the installation specification was written, the best information we were able to obtain indicated that for fields larger than 12,000 feet in perimeter, the multiple system would be more expensive than the series system. Subsequently it was found that these estimates were based upon unnecessarily expensive equipment for the multiple system and did not sufficiently consider operating costs. It therefore seemed advisable to make our own estimates of the costs of the series and multiple systems. In making these computations, it occurred to Mr. A. L. Lewis of our staff that a 550-volt multiple system with individual transformers at each unit might be less expensive than either the 230-volt system or the series system. We therefore included the 550-volt multiple system in our estimates. Figure 2 shows the costs, exclusive of labour costs, for installing a series system, a 230-volt multiple system and a 550-volt multiple system. Labour costs are omitted from these estimates because we have no means of determining what they would be. So

far as we have been able to learn, the labour costs of installing the series and multiple systems are equal and would not, therefore, affect the conclusions to be drawn from these figures. Figure 3 shows the total operating costs for the three systems. The unit costs assumed for these estimates are shown in Table I.

In computing operating costs, 10 per cent of the installation cost has been allowed for depreciation and 5 per cent of one-half the installation costs has been allowed

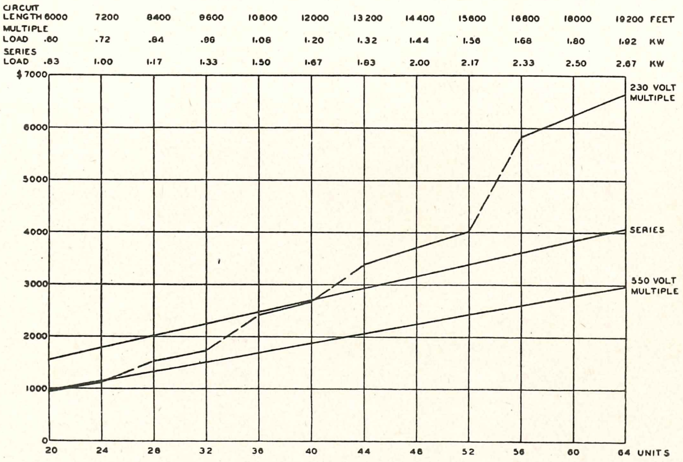


Fig. 2.—Estimated Cost of Materials required to Install three types of Boundary light circuits*.

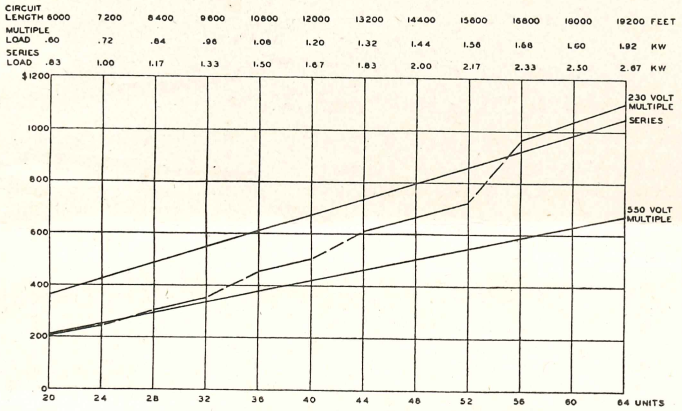


Fig. 3.—Estimated Annual Costs exclusive of Labour, for three types of Boundary Light Circuits*.

for interest. Interest has been allowed on only one-half the installation cost because the depreciation allowance will, in effect, cut the average amount outstanding during the life of the installation to one-half its initial cost. The exclusion of the labour costs makes the figures lower than they should be, but affects all of the costs equally. It is probable that the use of booster transformers, which would make it possible to use smaller wire for the 230-volt multiple circuits, would reduce the cost of such circuits slightly. We have not had an opportunity to investigate this.

In addition to the considerations of cost and candlepower, the choice of boundary-light circuits may be influenced by considerations of safety. Many airport engineers consider the multiple system safer than the series system because the maintenance of airport lighting equipment is generally entrusted to personnel who are not adequately trained in the use of the series system. It should also be pointed out that the multiple system, especially the 550-volt system, is more elastic and can be more easily extended to include additional lights than is the series system. In view of these facts and the results of our estimates of costs, it now appears that the choice of

*See explanatory statement and Table I for basis of estimates.

Table I

Unit Costs and Other Data Used for Estimates of Boundary Light Circuit Costs

	Series 6.6 Amp.	Multiple 230/115 v.	Multiple 550/110 v.
Lamps for clear units			
Type	St. ltg.	Gen. ser. cl.	Gen. ser. cl.
Lumens	320		
Watts	30	15	15
Life in hours	1333	1000	1000
Net cost (30 per cent off list)	$ .665	$ .140	$ .140
Cost/year	$1.995	$ .560	$ .560
Lamps for red and green units			
Type	St. ltg.	Tr. sig.	Tr. sig.
Lumens	1000		
Watts	65	60	60
Life in hours	1333	1333	1333
Net cost (30 per cent off list)	$ .455	$ .210	$ .210
Cost/year	$1.365	$ .630	$ .630
Lamp—weighted average (4 clear, 1 red, 1 green)			
Watts	41.7	30	30
Cost/year	$1.785	$ .583	$ .583
Cut-out films/year	$ .090		
Glassware			
Clear	$3.00	$3.00	$3.00
Green	4.00	4.00	4.00
Red	5.00	5.00	5.00
Weighted average (4 clear, 1 red, 1 green)	3.50	3.50	3.50
Assemblies			
Fixtures	$6.30	$2.50	$2.50
Cut-outs	10.35		
Transformers			2.00
Cones	9.00	9.00	9.00
Boxes		1.50	1.50

	Series 6.6 Amp.		Multiple 230/115 v.		Multiple 550/110 v.	
	Size	Cost/M	Size	Cost/M	Size	Cost/M
Parkway cable						
6,000-foot field	8	$93	12–10–12	$95	12–12	$91.80
7,200-foot field	8	93	12–10–12	95	12–12	91.80
8,400-foot field	8	93	10–10–10	122	12–12	91.80
9,600-foot field	8	93	10–10–10	122	12–12	91.80
10,800-foot field	8	93	8–10–8	165	12–12	91.80
12,000-foot field	8	93	8–10–8	165	12–12	91.80
13,200-foot field	8	93	6–10–6	200	12–12	91.80
14,400-foot field	8	93	6–10–6	200	12–12	91.80
15,600-foot field	8	93	6–10–6	200	12–12	91.80
16,800-foot field	8	93	4–10–4	290	12–12	91.80
18,000-foot field	8	93	4–10–4	290	12–12	91.80
19,200-foot field	8	93	4–10–4	290	12–12	91.80
Power						
Transformer, C.C.	2 kv.a.	$170.00				
	3 kv.a.	183.50				
Protector		60.00				
Fused cut-outs (2)		12.00				
Switch, magnetic		71.00		$30.00		$30.00
Power cost/kw.hr.		.03		.03		.03
Operation/yr. (hr.)		4000		4000		4000

Transformer losses are assumed to be 10 per cent of secondary load in all cases.

Explanation of estimates of boundary-light circuit costs

The estimated costs given in Figs. 2 and 3 are costs, exclusive of labour costs, for conventionalized circuits having the lights spaced at regular 300-foot intervals. The systems are assumed to include one-sixth red units, one-sixth green units, and four-sixths clear units. To facilitate computation the separate types are replaced by an average unit based on these ratios. These assumptions make no allowance for additional range-light units to distinguish runways from each other or

for obstruction lights on branch circuits. Where such lights are used in significant numbers, the total wattage should be considered. The power and material costs will generally lie between those corresponding to the perimeter of the circuit and those corresponding to the total wattage for the circuit. For multiple 230/115 volt circuits the smallest available wire giving less than 5 per cent voltage drop was selected. In every case 12.5 per cent of the material costs has been included in the annual costs to cover interest on and amortization of the original investment. These curves are only intended as approximate indications of relative costs and should not be taken as estimates for any particular field. Unit costs are given in Table I.

the series system for boundary lights is only indicated when the location of the field requires the higher candlepower obtainable with this system.

In setting up specifications for obstruction lights, it was apparent that the angles and distances from which these lights must be visible bore very much the same functional relationship as in the case of boundary lights. It was therefore considered that the candlepower distribution required for the boundary lights was also appropriate for the obstruction lights, except that in the case of obstruction lights on relatively high obstructions it would be advantageous to have the maximum candlepower more nearly horizontal. The candlepower distribution specified for obstruction lights is, accordingly, the same as that specified for the boundary lights, with the axis of the maximum candlepower adjusted in three steps to accord with the height at which the unit is to be used.

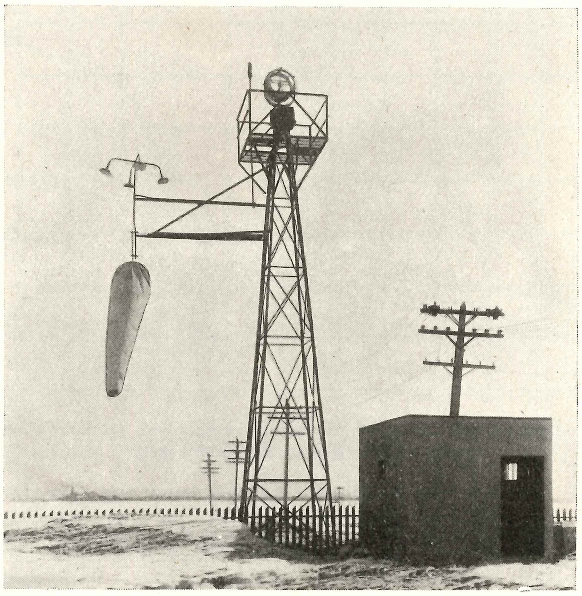
At the time when the specifications were being prepared, field approach lights and contact lights had already demonstrated their value. Nevertheless, in view of the lack of any general agreement as to what types of lights were most suitable for these applications, the lack of commercial units giving even approximately the candlepower distribution which seemed theoretically desirable, and the lack of data on the performance of those commercial units which appeared most promising, it appeared advisable to put no specific requirements for field approach lights and contact lights into the original specifications. By the time these specifications had been released, however, new developments in the field of contact lights and candlepower data on their performance had become available and a specification for contact lights has now been issued as a separate specification.

Wind Indicators and Ceiling Projectors

The requirements for wind cones permit the use of either internally- or externally-lighted wind cones, but require that internally-lighted cones shall be made in accordance with the standard design of the Air Navigation Division.

The wind tee most generally used in the United States is 12 feet across the head and 23 feet along the stroke. These dimensions do not conform to the recommended standards of the International Commission on Illumination, which stipulate a wind tee 4 meters, approximately 13 feet, in both dimensions. Pilots in this country seem to favour a tee having the stroke longer than the head, but no evidence was offered to show that so great a difference as a 23:12 ratio is desirable. The specification has, therefore, been worded broadly to permit a wind tee 12 by 18 feet, or any larger tee in which the length of the head does not exceed two-thirds the length of the stroke. This permits the use of a 12 by 23 foot tee, but does not prevent the development of a new tee approximating somewhat more closely to the dimensions recommended by the I.C.I. The lighting of the tee may be either by incandescent lamps or by means of green gaseous-discharge tube lamps. While the use of gaseous-discharge tubes for wind tees has not been very common in this country, it has been popular in Europe and it was therefore felt desirable to leave the way open for the development of such wind tee illumination in the United States.

The ceiling projector is another unit which could not be as satisfactorily specified as was desired. If any scientific tests have been made to determine the proper candlepower characteristics for a good ceiling-light projector, the results were not available to the writers of these specifications. Ceiling projectors, however, are indispensable items of equipment for many airports and it was therefore deemed advisable to include them in the specification. The requirements stated in the specification are based on the



Courtesy of Canadian General Electric Co.

Fig. 4.—Winnipeg, Man. Airport, showing 24-inch Revolving Beacon and Externally Illuminated Wind Cone on 51-Foot Steel Tower.

specification then in use by the Weather Bureau. The Weather Bureau has, however, arranged with the Bureau of Air Commerce to have the characteristics of ceiling projectors analyzed as one of their projects at the National Bureau of Standards to determine whether the present design is the most satisfactory that can be made. At the conclusion of this study it may be possible to prepare more satisfactory requirements for ceiling projectors.

The specifications make provision for automatic photoelectric control of the airport lighting, but the Airport Section does not feel that any special emphasis should be laid upon this type of control at this time.

Landing-area Floodlight Systems

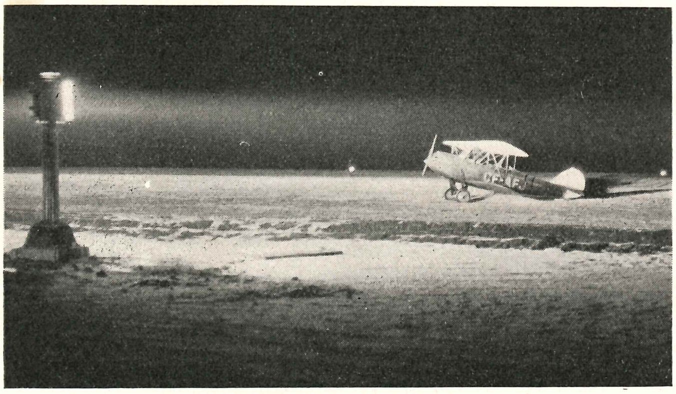
In preparing the requirements for landing-area floodlights, it was felt that the most important consideration was the prevention of glare. It has been the history of all lighting developments that in their early days the tendency is to devote nearly all of the attention to means for increasing the amount of light available. After a period of attempting to make things visible by radiating as much light as possible with little regard for how much shines into the eyes, illuminating engineers again demonstrate that in this new application as in older ones the eyes will readily accommodate themselves to low illumination if they are protected from the glare of naked light sources. It is generally conceded that good pilots can land safely with the very low illumination available from bright moonlight if there are no disturbing lights in sight. On the other hand, a pilot with a bright glaring floodlight in his eyes is in danger of making a false estimate of the ground level regardless of how well lighted the ground itself may be. The first consideration, therefore, in planning a landing-

area floodlight system is to make certain that the installation will not increase the hazard by introducing glare.

Three methods of avoiding glare in landing-area floodlighting are available. With a decentralized system properly designed, it is possible to obtain adequate illumination by using only those units of the system which will illuminate the ground from such angles that glare is avoided. If the lighting is accomplished by a single unit, it is possible to introduce a movable shadow-bar which, with careful control, will entirely shield the eyes of the pilot from a view of the light source. The single-unit shadow-bar system has the disadvantage of suddenly introducing a hazard in case of any failure to keep the shadow on the pilot. It is also disadvantageous when the airplane is landing against the light because the pilot must look at the unilluminated side of the blades of grass, sticks, stones and other material which makes up most of the ground surface. On the other hand, there are available single-unit landing-area floodlight systems which give a higher intensity and greater uniformity of illumination than is generally achieved with the decentralized units. On some fields this system also proves to be the less expensive, because of the great saving on cable costs.

The third method of avoiding glare is to use a mobile single unit and to locate it according to the existing wind. This method has been successfully used in Europe, but has never been seriously tried by any commercial airport in this country.

Next to the avoidance of glare, uniformity of illumination is perhaps the most important characteristic of a good landing-area floodlight system. This characteristic is considerably emphasized by airport lighting engineers in Europe, but the lack of sufficient experimental data made it impossible to write an adequate specification to control the uniformity of the illumination. No experiments have been carried out in this country to show whether it is sufficient to limit the spread between the highest and lowest illumination levels on a landing area, or whether it is more important to control the gradient of illumination from point to point over the surface of the landing area. It was therefore deemed advisable to confine the specifications to a requirement that the candlepower characteristics of any floodlighting system proposed for an airport be furnished in such a form that the airport engineers can



Courtesy of the Canadian Westinghouse Company Limited

Fig. 5.—Floodlighting at Saskatoon, Sask. Airport.

determine, with the aid of a contour map, what shadow areas will exist. To accomplish this, provision was made for vertical isolux curves plotted with the vertical distances exaggerated.

For small fields these isolux curves are to be plotted with a horizontal scale of 100 feet to the inch and a vertical scale of 10 feet to the inch. For larger airports the horizontal scale is decreased to 200 feet to the inch, but the vertical scale becomes 20 feet to the inch. By plotting the contour of the airport along any line radiating from the floodlight to the same scale as the vertical isolux curves and superimposing the isolux and contour curves the points of intersection projected back on the radial line give the locations along that radial line at which the illumination will have the intensities represented by the isolux curves. The minimum illumination allowable for the landing area has been increased from 0.15 foot-candle to 0.20 foot-candle. This is a compromise between the old requirement and the value of 0.25 foot-candle which has been recommended by the Committee on Aviation Lighting of the I.E.S. It is in substantial agreement with the value 0.19 foot-candle recommended by the I.C.I. at its sessions in Karlsruhe in July, 1935.

The old airport rating regulations required that the whole landing area should be illuminated. No adequate reason for this requirement is known, especially in view of the fact that oftentimes the landing area exceeded that required for the rating given. Moreover if decentralized lighting is used satisfactory landings can be made when only the landing strip on which a landing is about to be made is floodlighted. The floodlighting of a wider area gives a better perspective but this does not seem indispensable. The specification therefore was worded to require an elliptical illuminated area not less than 3,000 feet long and 500 feet wide, with a provision for increasing the length of the illuminated area in the case of airports located at high altitudes.

Another desirable characteristic in a landing-area floodlight is a sharp cut-off on the upper side of the beam. The specification contains a requirement that the intensity shall "be reduced to 10 per cent of the maximum intensity within 3 degrees." This is not as sharp a cut-off as is desirable, especially if there is slight haze in the atmosphere, but there are so few commercial floodlights that can qualify for a narrower upward divergence that a closer requirement was not warranted.

Aviation Colours

Prior to the issuing of the performance specification, the only official definition of aviation colours in the United States applied solely to red and green airplane position lights. These definitions were stated* in terms of dominant wave-length and purity with no reference to which of several possible sets of constants were to be used in determining these values. The present performance specification defines aviation red, yellow, green, and white in terms of the Standard Observer and Co-ordinate System adopted by the International Commission on Illumination at Cambridge in 1931. The definitions are illustrated by a diagram which has been reproduced as Fig. 6. For the convenience of those who are not familiar with the I.C.I. co-ordinate system, the specifications also interpret the fundamental definitions in terms of dominant wave-length and purity except for aviation "white" which is described in terms of familiar light sources.

It is impracticable to inspect any quantity of service glassware by a direct application of the fundamental definitions. To overcome this difficulty testing definitions have been included in the section on aviation colours. These definitions are based on the National Bureau of Standards' primary standard filters for aviation colours.

To assist manufacturers, provision is made for certifying working standards which give colours within the fundamental definitions and conform to certain physical requirements. This procedure seems more equitable and more practical than requiring that working standards be replicas of the primary standards; more equitable

*Airworthiness Requirements for Aircraft Components and Accessories, Aeronautics Bulletin 7-F, p. 8.

because some manufacturers might have difficulty in producing replicas of the primary standards and more practical because the working standards can be made of the same type of glass as the service glassware to be tested and this simplifies the colour comparisons which must be made in the course of inspecting the glassware.

The fundamental definitions adopted in the performance specification are more restrictive than those adopted

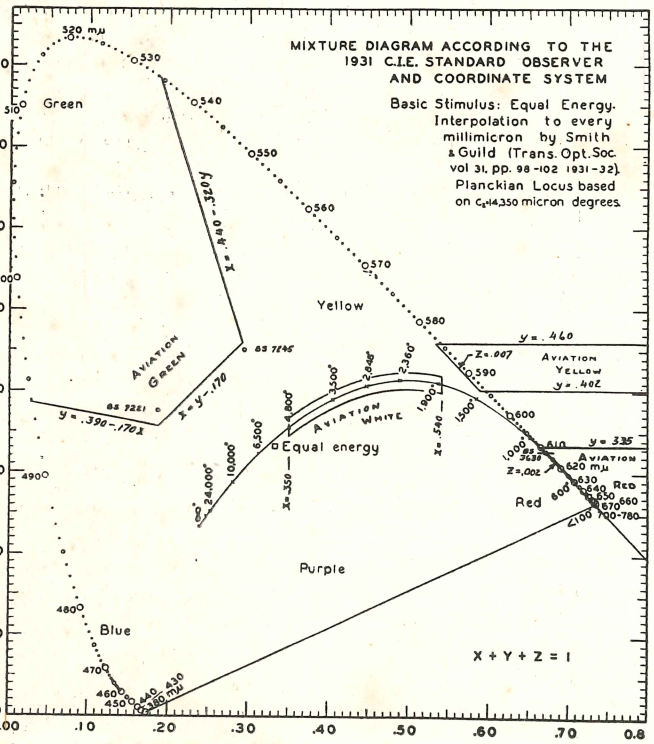


Fig. 6—Diagrammatical Representation of Acceptable Aviation Colours.

by the I.C.I. at Karlsruhe in 1935. This restrictiveness is dictated by caution rather than experience. It did not seem prudent to broaden the requirements beyond what had been previously found satisfactory. Research on proper limits for aviation colours is now in progress with funds supplied by the Air Navigation Division of the Bureau of Air Commerce. It is hoped that these experiments will definitely establish what limits for aviation colours are safe.

Photometric Measurements

Under the caption "Photometric Measurements" the performance specification sets up a standard procedure for measuring the candlepower distribution of aviation lighting equipment purchased under these specifications. This equipment is usually of one of two types, projectors giving highly-concentrated beams, or units having horizontal annular prisms which give a candlepower distribution approximately the same at all angles of azimuth.

The requirements of the performance specification differ in several particulars from those of the "I.E.S. Standard Testing Specifications."* These differences arise both from the higher concentration characteristic of the aviation lighting equipment and from the fact that we are interested in the visibility of the light rather than its capacity to illuminate other objects. For these reasons it is not sufficient to obtain average values of intensity over solid angles of appreciable size and it is necessary to make the measurements with much longer photometric distances than those which suffice for floodlights. Instead of a fixed minimum testing distance, the performance specification gives the minimum photometric distance by Benford's formula† in terms of the diameter of the unit and the minimum angle subtended by the source as seen from the reflector or lens.

This review of the Standard Specification for the Installation of Airport Lighting Equipment and Materials and the Performance Specification for Airport Lighting Equipment and Materials covers the novel aspects of these specifications so far as the writer is competent to do so. For the most part, the requirements of the specifications relating to wiring and wiring devices merely insist on adherence to what is generally recognized as good wiring practice.

*Trans. I.E.S. 28, 479 (1933).
†Gen. Elec. Rev. 4, 230 (1923).

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